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LIFE AND EVOLUTION

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Frontispiece.

Gulls at Port Erin.

LIFE
AND EVOLUTION

BY

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"PROBLEMS OF EVOLUTION"
AND "THE STRUCTURE AND LIFE OF BIRDS"

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Preface

THIS book has grown out of lectures delivered to the Haileybury Natural Science Society. From the nature of the case, therefore, it aims at being intelligible without the help of much preliminary knowledge. Some of the lectures, however, were delivered to a small number of the elder members of the society, and the subject matter of some of these was in itself rather difficult. My object has been, not to shirk difficult questions, but to make them clear to anyone who will give his attention to the subject. All the chapters have gone through several processes which ought to result in lucidity. First, the subject matter of them has been got into shape for lectures, in most cases more than once, never reappearing without rearrangement. They have then been typewritten and submitted to my friend, Mr O. L. V. Simpkinson, who has very kindly read them from end to end and made suggestions. Some of these suggestions involved additions and a good deal of rewriting. Finally, I have myself reread the book and recast what seemed not to be clear. Everything has been done, by means of headings to sections, references to pages in the table of contents, and a fairly complete index, to make it easy to find one's way about in the book.

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I am here partly on the same ground as in my *Structure and Life of Birds* and *Problems of Evolution.* But most of the matter is new, and, where it is not, I have rewritten and rearranged everything.

Hesiod quaintly observes, "The best man of all is he who discovers everything for himself." It is impossible for any man in modern times to live up to this ideal, more especially for a man whose profession is only too truly described by the words "ne otium quidem otiosum est." Still, in every chapter I have depended very largely on my own observations.

I owe a debt of gratitude to Mr E. T. Browne for helping and encouraging me in photography — the photographs that illustrate the book are my own— and in the study of marine zoology. My thanks are also due to the following members, past or present, of the Haileybury Natural Science Society for help ungrudgingly given: to C. G. C. King and I. C. Maclean, the merits of whose drawings I hope my readers will appreciate; to O. L. V. Simpkinson, for services which I have already mentioned; to J. H. Mason, A. T. Woolward, and J. E. B. Potter, to whose skill I owe some of the minor illustrations, mainly diagrams; and lastly, to A. R. Gidney, who has put much zeal into the work of reading the proofs.

A few of the illustrations are borrowed by the kind permission of the authors or publishers of the books from which they are taken. In every case the source is acknowledged beneath the figures and in the list of illustrations. Some are reproductions from the original electros, some are photographs from the original prints —[*Ph.*] is then added.

In the list of illustrations the initial letters of the surnames of the draughtsmen who have contributed them are given in brackets (*M.* = I. C. M.—*J.M.* = J. H. M.). *Ph.* stands for Photograph.

F. W. HEADLEY.

HAILEYBURY, *August* 1906.

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LIFE AND EVOLUTION

Chapter I

PLANTS AND ANIMALS

Difficulty of definition

WHAT would be the commonest answer if we were to ask a number of people who had not given the subject very much thought, What is the difference between a plant and an animal? No doubt all sorts of answers would be given, but the commonest, I think, would be that animals move while plants do not. Everyone has noticed that an oak tree is always at home, whereas if you draw a cover, the fox is very possibly not at home. Put a ferret down a rabbit hole, and very possibly he reappears almost directly to tell you that at present it is untenanted. Our everyday experience naturally leads us, before we properly investigate the subject, to the conclusion that *all* animals move, and that *all* vegetables are stationary. But, as a matter of fact, some organisms that are without doubt vegetables have the power of motion—the whole organism moving, and not only a tendril or a shoot—while there are not a few animals that spend the greater part of their lives anchored to rocks or sea-weed or reeds.

We, therefore, want new definitions to enable us to distinguish plants and animals. Here is something definite and decisive: an animal must have organic food—vegetable or animal food, that is. A vegetable, on the other hand, lives on inorganic food. Its diet is neither vegetable nor animal, but it gets the carbon that it wants from the air, and its mineral salts from the soil. The animal has its food worked up into shape for it by other living creatures. The vegetable, for its nourishment, depends on the air, the sun, water, and the soil.

Protoplasm

We must now consider what both have in common. They are both made up of a substance called protoplasm. It is difficult to say what protoplasm is. We can say, without fear of contradiction, that it is the basis of life, for it is the material of which all living creatures are built. But when we come to analyse protoplasm we are met by an insuperable difficulty. It is essentially alive, but the chemist can only analyse what is dead. He breaks up protoplasm into its components, and finds them to be carbon, oxygen, nitrogen, hydrogen, sulphur (I arrange them according to the amount each contributes), together with some minerals (phosphates and sulphates of potassium, calcium and magnesium), small in amount, but essential, like that little unknown something in Dr Jekyll's prescription, that made all the difference, and a large proportion of water. This is what is found in dead protoplasm or, to put it more properly, in what a short time before was protoplasm. It is a mere corpse that the chemist breaks up into its component elements. If he maintains that he has analysed protoplasm, he has less insight into realities than the grave-digger in *Hamlet*:—

> *Hamlet.* What man dost thou dig it for ?
> *First Clown.* For no man, sir.
> *Hamlet.* For what woman, then ?
> *First Clown.* For none, neither.
> *Hamlet.* Who is to be buried in it ?
> *First Clown.* One that was a woman, sir, but rest her soul, she's dead.
> *Hamlet.* How absolute the knave is!

It behoves us to be "absolute" when speaking of scientific matters, and here we have to do with a very essential difference. Protoplasm, as long as it is itself, has certain unmistakable properties. It is irritable or excitable, *i.e.* it reacts in response to an external stimulus. When a man, during sleep, protrudes a foot from underneath the protecting bed-clothes, the cold will very likely so act upon the foot that the sleeper without awaking withdraws it. If we accidentally lay hold of a nettle, we very quickly draw back our hand. The leaf of a sensitive plant when touched droops and each lobe of the leaf folds up. Any ordinary tree when clipped responds by sending out a number of shoots to replace the old. When caterpillars half strip an oak tree a second crop of leaves appears during the same season. Put a stone on the mouth of the sea-anemone and he at once begins to take steps to shovel it away. Put before a keen investigator a book that deals with his favourite subject and he reads it with avidity. In the same way (to descend almost to the bottom of the scale) a one-celled animal, when he comes in contact with some microscopic plant that suits his taste, will set to work to swallow it. I have now given a number of instances of the irritability or excitability of protoplasm. It has another characteristic that distinguishes it from inorganic substances. When circumstances are unfavourable, decomposition sets in, it breaks up, and, to use the word which is used of nothing else, dies. If it is to continue protoplasm, it must under ordinary circumstances be constantly assimilating, taking in food, that is, and building it into its own substance, while other used-up matter is got rid of. Some low organisms have times of torpor during which the processes of dilapidation and rebuilding, of wasting and repairing, are in abeyance. After a while they return to a life of activity, reducing their substance by wear and tear and making good what is lost. The new stuff taken in, however unlike the substance of the plant or animal whose food it forms, is soon assimilated and made like it. Thus animals, and, in a more sluggish way, plants, are, but for the periods of torpor of which I have spoken, in a continual state of flux. There is a ceaseless wasting away, a ceaseless renewal by means of food. An animal has been compared to a ripple which keeps the same shape, but is formed from moment to moment of different particles of water, that pass in turn a stone lying at the bottom, that ruffles the surface. A jet in a waterfall is another good illustration, and perhaps an even more striking one. In fact, nothing can be more unstable than protoplasm, though in some organisms, as we have seen, it is capable of remaining torpid for a time. In its ordinary condition it does not rest. It must be perpetually taking in food and getting rid of refuse, or it dies and ceases to be protoplasm. It is this taking in and assimilation of other substances that makes an organism grow. If the waste is less rapid than the intake, growth must ensue. And it is no mere accretion, no mere overspreading of the old substance with fresh coatings, as a stalactite hanging in a limestone cave grows through the water trickling over it and leaving fresh deposits. It is growth from within through the organism laying hold of new material, making it like to its own substance, and, so to speak, wedging in the new matter among the old.

Protoplasm, whether vegetable or animal, is formed of cells, small particles or blobs of protoplasm. In the vegetable the cells have a definite cell wall, formed of a substance called cellulose, which is nearly akin to starch. The animal cell, on the other hand, has for a wall only the most delicate cuticle, and in some cases this is absent altogether. The cell, whether animal or vegetable, has a nucleus, the central citadel of its life. Often, if the nucleus is to be seen clearly, the cell must be stained. When this is done, it is found that a small speck, the nucleus, is stained darker than the rest. The cell has a life of its own. It multiplies by fission, that is, by dividing into two parts, and when fission takes place, the nucleus divides, half going to each daughter cell. But the term daughter cell is misleading, for it is impossible to distinguish between parent and child. The unicellular organisms are, therefore, in a sense immortal. Those existing now are small fragments of those existing long ago. But this immortality is conditional. When fission has gone on for a long while, the cells become impoverished and exhausted, and in time death will ensue if they be not somehow rejuvenated. If an organism belonging to the same species, but not to the same lot—not sprung recently from the same individual—be introduced, it will combine with one of those who have been exhausted by long-continued fission. This combining of a one-celled organism with another is called conjugation. It brings with it a renewal of vigour, and when it has taken place fission begins again and goes gaily on.

We now know a good deal about protoplasm. It is irritable or excitable. It is unstable, and if the conditions are sufficiently unfavourable, it breaks up and decomposition ensues. It is

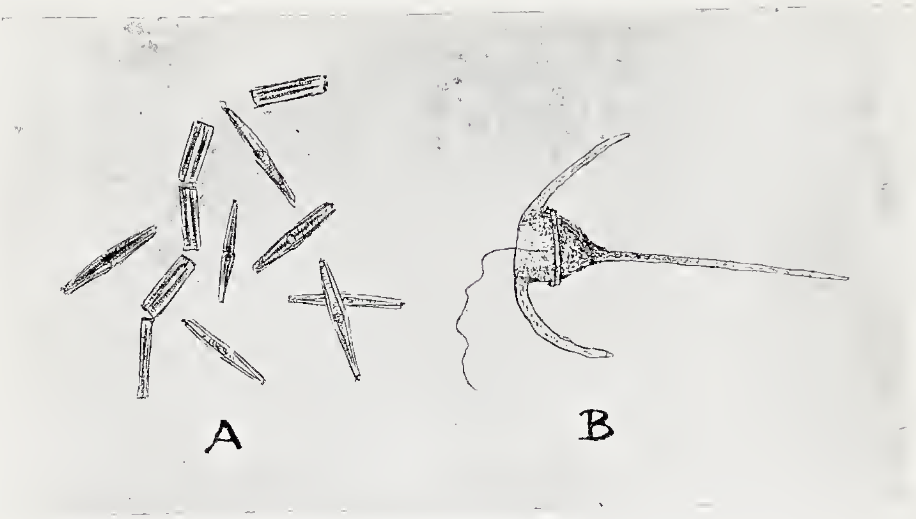

FIG. 1.—A, Diatoms, common fresh-water species (×500 diameters); B, Ceratium Tripos, a large marine Infusorian, swimming by means of a flagellum.

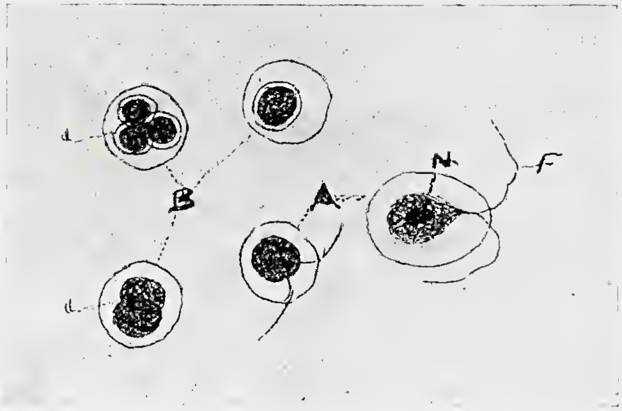

FIG. 2.—Protococcus pluvialis (×500 diameters)—A, motile phase; B, resting phase, showing process of division: only three of the four daughter cells (*d*) are shown here; N, nucleus; F, flagellum.

Facing p. 5

formed of cells, and these cells multiply by fission, the nucleus always taking part in the division and going half to one daughter cell and half to the other. To the one-celled organisms, when repeated fission at last ends in exhaustion, conjugation brings new vigour.

So far I have described mainly the characteristics that vegetable and animal cells have in common. I will now take a few common types of plants and animals very low in the scale, and follow out their life histories as far as they are known. This will bring out the difference between the two classes of organisms.

Typical Organisms

The diatom

There are very minute plants called Diatoms, so minute that they require a moderately high power of the microscope to see them. They may be found in any pond, and are especially common among the sphagnum moss that covers large stretches of moorland country with a spongy carpet that is sometimes green, sometimes reddish yellow. A Diatom is a single cell of protoplasm enclosed in a flint casing formed of two valves which fit together like a pill box and its lid (fig. 1, p. 5). (Diatom means cut across, so called because of its two valves.) A great many, some of them rather larger than the common fresh-water ones, may be found floating in the surface waters of the sea, floating in spite of their flint casing, because, I believe, of the oil they contain. There is an endless variety of forms, and the Quekett Club have, I am told, a collection numbering over 10,000 species. At the bottom of the Antarctic Ocean, covering great stretches, there is a Diatom ooze formed mainly of the shells of these microscopic plants, the numbers that go to the formation of a cubic foot of the ooze being altogether beyond calculation. In the British Museum at South Kensington may be seen a great block formed of Diatom shells, all of marine species. The block has been cut from a Diatom stratum twenty-five feet thick that extends over a large area of country near Richmond, in Virginia.

In every Diatom there is, colouring part of its tiny area, some brown, yellowish, or green pigment. The coloured substance, however it may vary from green to yellowish or brown, is that which makes ordinary plants green. On this substance, called chlorophyll, their very life depends. Chlorophyll has a unique power. It enables plants to take carbonic acid out of the air, to separate it into carbon and oxygen, give off the oxygen, and make the carbon part of themselves. But chlorophyll will act thus, only when it is aided by the sun's rays. What really happens is this: the plant by means of its chlorophyll appropriates to itself the radiant energy of the sun. This is a power peculiar to plants. No animal, qua animal, unless, that is, he belongs to some very low class that have some definitely vegetable characteristics, has any chlorophyll, or the power which chlorophyll confers. Other nourishment, other than the carbon got from the air, the plant obtains by absorbing mineral salts in a state of solution. It has no mouth, and none is required for its system of eating. The nourishment soaks through the cell wall, and partly, in the case of the Diatom, finds admittance where the two valves fit together. Neither is there any anus for the ejection of indigestible matter. The oxygen given off passes through the flinty casing or between the valves.

Chlorophyll

No man of science maintains that the Diatom is an animal, and yet it has the power of moving. It slides along with continual stoppages, each slide extending over a very short distance. This movement is easily visible under the microscope, but even under a quarter-inch glass the slides are very short and do not follow one another very rapidly, so that the pace, though multiplied as many times as the diameter of the Diatom is multiplied—about 240 times—is very slow. How it moves is not known, for the threads of protoplasm which it is said to protrude and use as oars may be non-existent. Biologists sometimes, like the "scurvy politician" in *King Lear*, "seem to see the thing that is not."

The very slow movements of the Diatom must be of some use to it. The pace is so slow that very little distance can be covered, and therefore, in travelling, the Diatom must trust mainly to winds and currents. However, its power of movement may save it from getting covered with mud when it lies at the bottom. Moreover, in spite of the flint envelopes, conjugation takes place, and without power of movement this could hardly be.

Proto-
coccus

Protococcus is a microscopic green organism, found in rain-water puddles and said to be common there (fig. 2, p. 5). I can generally find it in pond water, but failing this you can buy a tube containing it from a dealer.[1]

A pink form of it, often called the "snow-plant," can frequently be seen colouring the mountain snow in Switzerland. Once the well-known pink tinge was observed in a garden near Ware on the winter snow, and it was found that the colour was due to myriads of Protococci.

Protococcus has an outer transparent envelope that may escape notice if it is not very carefully inspected. In the fluid within this envelope is a small disc of green, tending at one place to a point. From this point spring two flagella or little whips which pierce the outer envelope and, lashing the water, enable Protococcus to travel at what appears, under the microscope, a brisk pace. It has been calculated, however, that its maximum pace is about a foot in a quarter of an hour. But this is racing speed compared with that of a Diatom. After leading an active life for a time, Protococcus drops its flagella, and forms round itself an envelope of cellulose[2] called a cyst, the organism being described when in this state as encysted. Many small organisms pack themselves up thus and remain dormant for a time. But Protococcus is not inactive during this sedentary phase, for it is then, and only then, that it multiplies. Its protoplasm divides into two, and each half again into two, so that four young Protococci are ready to face the world.

Over Protococcus there has been much wrangling. Is it a plant or an animal or betwixt and between?

Its flagella seem to connect it with a number of infusoria which are undoubtedly animals. Moreover, a form of Protococcus found in lakes (but not this rain-water or pond form) has a space in its body which can be seen to contract and expand (hence called a contractile vacuole), which has to do with the getting rid of waste, and this is certainly an animal characteristic. On the other hand, Protococcus lives on inorganic food only. It takes in carbonic acid that it finds in the water of its pond, and, besides this, various mineral salts, which are also found in solution in the water where it lives, and which soak through its envelope. No animal lives in this way. Animals have mouths and use them to swallow protoplasm. No soaking of dissolved salts through their skin, no absorption of gases will satisfy them. The animal appetite demands protoplasm, demands, that is, animal or vegetable food. I therefore put Protococcus unhesitatingly among the vegetables because of its diet. This to my mind is decisive. But we may throw in this, that its envelope is formed of cellulose, a substance normally belonging to vegetables, in animals to be noted as something exceptional.[1] True, the contractile vacuole in the lake form of Protococcus is a feature ordinarily found in the simplest forms of animal life. By what is called convergent evolution it has been developed in a plant, in Protococcus to wit, which remains a plant all the same.

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[1] *E.g.* from Mr T. Bolton, 25 Balsall Heath Road, Birmingham.

[2] A substance allied to starch.

Volvox Globator

Common in ponds, so common sometimes that the water is green with it, is the beautiful Volvox Globator (fig. 3, p. 8). It is a small, green, hollow ball made of a network of cells, and it keeps rolling slowly over and over. The reason of its rolling requires some finding out. Each cell has attached to it two minute flagella, and the rhythmical waving of these produces the rolling motion. This is the most wonderful thing that we have yet had under consideration. All these flagella keep time as perfectly as eight oarsmen in a boat ever kept it, or perhaps even more perfectly, and there is no central organ, no brain, to direct them and maintain the rhythm! To see the flagella, reduce the light by means of the iris diaphragm if your microscope has one. They ought then to be visible. Often young Volvoxes, half a dozen or more, can be seen within a parent sphere, and when this breaks, they start life on their own account. These daughter colonies are formed in this way: certain special cells, bearing no cilia, divide into two, then into four, eight, sixteen, and so on,

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[1] The cellulose envelope turns slightly bluish in Schultze's solution, which contains iodine.

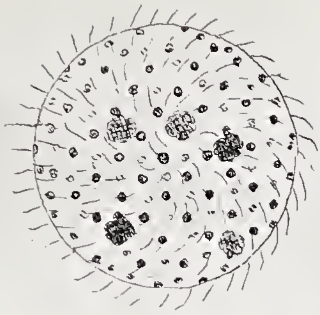
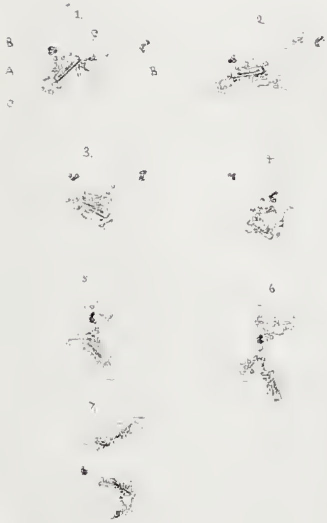


FIG. 3.—Volvox globator (×60 diameters). Daughter colonies are swimming within the sphere. The flagella are moving all in one direction. Each cell has really, like a Protococcus, two flagella.



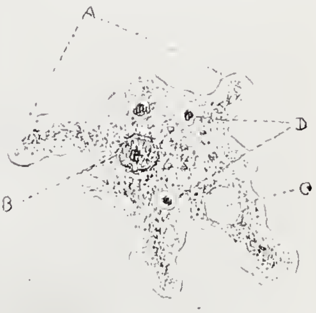


FIG. 4 (1).—Amœba proteus (×60 diameters). Showing ingestion of food particles and, below, propagation by fission. Observed at intervals during half an hour. A, diatom ingested; B, food particle; C, contractile vacuole.

FIG. 4 (2).—Amœba proteus (×400 diameters)—A, pseudopodia; B, nucleus; C, contractile vacuole; D, food in vacuole.

till no more division is required. The daughter colonies are ready formed when the parent sphere breaks. But this is not the only way of reproduction. Certain sexual cells develop. By the conjugation of a male and female cell, a sperm and an ovum, an oosperm (the beginning of a new colony) is formed. This divides and divides, but keeps all its cells together till at last a complete Volvox is there and goes rolling over like its parent. Within it may often be found a kind of rotifer (wheel animalcule), which seems to lead a parasitic life within the Volvox. How does it gain admittance? There is no rupture in the network of cells.

In Volvox we see a great step onward. When Protococcus divides, the cells remain separate. In Volvox they adhere together, and there is a multicellular organism. Moreover, there are various kinds of cells: (1) the ordinary flagellated cells; (2) the unflagellated, which divide and form daughter colonies; (3) the sexual cells.

Here once more we have the question to ask and to answer if possible—animal or vegetable? The diet is the same as in the case of the Diatom and Protococcus, carbonic acid gas from the water, and mineral salts in solution, soaking through the cell walls. There is chlorophyll, the distinctive property of vegetables, to digest inorganic food. But what of the mode of reproduction? Plants bear pollen and ovules, and so in them sex is represented. But here reproduction is more definitely animal-like and not plant-like. Still the mode of taking nourishment is decisive. Volvox feeds like a plant on inorganic food. Besides this it throws off buds (daughter colonies) in vegetable fashion. It is a plant, in fact, which in its sexual form of reproduction is animal-like. We are bound, therefore, in my opinion to label it a vegetable. The reason for this will appear more clearly later on. But I must remark here that I am more consistent than those who would make Protococcus a vegetable, and Volvox, which is a colony of Protococci, an animal.

I now take an organism found on dead leaves and other things in ponds and tanks—I once found it thick in an upstairs cistern—an organism that is indisputably animal, the far-famed Amœba, Amœba so called because it is so protean in its changes of form (fig. 4, p. 8). It is a mere blob of jelly. When active, as it often is, it throws out tongues or fingers in various directions. Its movements are more like flowing than anything else. First, the transparent margin streams out, then the grey granulated interior flows into the protruded finger. When it comes into contact with anything edible, for instance a Diatom, it will close round it, and often several Diatoms are to be seen in the interior undergoing digestion. But—a thing to set one thinking—if he knocks against something inedible, even though it is smaller than a Diatom, he will leave it alone. (I cannot help personifying the Amœba when describing this wonderful discrimination of his.) He distinguishes things, in fact, by some power of sense, though he has no sense organs. He digests too, though he has no localised stomach. One special organ he has, a contractile vacuole, which suddenly contracts and slowly re-opens. Its work is to get rid of water which Amœba swallows with his Diatoms and other food. The surface generally helps in ejecting waste products. Like the organisms we have just investigated, Amœba multiplies by fission, half the nucleus going to each of the halves. Whether conjugation ever takes place is not known, for it has never been observed, so far as I know, but that it does is extremely probable. In hard times (for instance, when the water dries up) Amœba forms round himself a cyst, not of protoplasm, but a lifeless envelope, just as a snail secretes from himself, as he grows, a lifeless shell. Probably the cyst consists of a substance resembling horn, certainly not of cellulose, the vegetable substance of which Protococcus builds the envelope in which he encases himself. Thus encysted, Amœba lives torpid for a time, his protoplasm, if it wastes away at all, wasting very slowly, and consequently requiring no replenishing by means of food. But the fact that his cyst is not of cellulose is not the great and most striking proof that Amœba is an animal. That we find in his method of eating. Though he has no mouth in the ordinary sense, yet practically he has one, for he swallows his food in lumps, opening a mouth at the particular point at which he comes in contact with something edible and appetising. But we must be careful how we apply our ordinary terms to him. His eating is the taking of food into an individual cell, a process similar to that which goes on in our alimentary canals, where we have many cells that play the part of Amœbæ, seize small morsels of food and ingest them. To this process our eating is a preliminary. When masticated and swallowed, the food has still to be admitted to the life of the cells of which our complex organism is built up. Amœba has not what we call a mouth. Eating, as we practise it, is impossible to him. But undoubtedly he takes in gobbets of food and enjoys them. It is no mere percolation of dissolved mineral salts, no absorption of carbonic acid through a cell wall. It is an animal process of eating, but the simplicity of the Amœba organism combines in one what in us are two processes, viz. eating and the appropriation by individual cells in the alimentary canal of the food that has been prepared for them. Moreover, Amœba's food is organic, is protoplasm, Diatoms for instance, to mention his favourite dish, or encysted Euglenæ. He has no chlorophyll, and consequently no power of getting the carbon he wants from the carbonic acid gas in the water. The animal nature requires that its food shall have already been worked up for it into protoplasm by some vegetable or other. Taking the complicated, delicately-built protoplasm into his jack-of-all-trades, now doing duty as a stomach, he first breaks it up into simpler substances, then rebuilds it into protoplasm, and it is a part of himself. Thus he carries on within his one cell the processes of digestion and assimilation—in fact, all the elaborate changes which in us are the work of the stomach and other digestive organs and of the blood. In the Diatom and Protococcus there is no preliminary breaking up. They take the crude inorganic material (carbon got from the air, mineral salts from the water), and set to work to build it up into protoplasm. By Amœba, since he is an animal, the built-up product is taken, broken up, and rebuilt.

There is, too, another important difference between the two worlds that we are contrasting, the animal and the vegetable. It has to do with the gases they absorb or give off. An animal is a slow furnace, always burning himself up. He is always breathing in oxygen and oxidising his tissues, *i.e.* the stuff of which he is built. It is the burning that gives him his warmth and his energy. In his small way the Amœba breathes, gets oxygen from the water and oxidises his one cell of unparticularised protoplasm (nerve and muscle and everything all in one). When he moves he generates heat and loses weight, as we do when we take exercise. Arguing from analogy, we infer that he generates heat. We cannot test it. But finding him like other animals in other respects, we conclude that he is like them in this also. Unfortunately we have no thermometer that will test the fluctuations of so minute a creature. His breathing, then, carried on by the whole of his surface, consists in taking in oxygen, oxidising his protoplasm, and giving off the carbonic acid gas that results from the burning. This process of breathing goes on, though more sluggishly probably even than in Amœba, in Protococcus and other plants. They, too, oxidise their tissues, and give off carbonic acid gas. So far they are like animals. But plants feed by a reverse process. They absorb carbonic acid gas, break it up into carbon and oxygen, build the carbon into their system, and get rid of the oxygen. Nothing similar to this takes place in Amœba. No animal gives off oxygen. On the contrary, all animals absorb it, and give off carbonic acid gas in its place.

I will take now one of the Infusoria, one-celled animals, provided with cilia, minute threads of protoplasm, by means of which they swim.[1] Many can be found in any pond. The one I take is a very common one, known by the name of Paramœcium aurelia, and familiarly called the Slipper Animalcule (fig. 5, p. 12). It is much larger than Protococcus, being often $\frac{1}{100}$ of an inch in length. It has a mouth and swallows small particles of food round which vacuoles form, the course of the particles being distinctly visible within the animal's one cell. Having a mouth and taking its food in lumps, albeit small ones, it is undoubtedly an animal. But there is another species of Paramœcium which is very common in the small ponds near Hertford and, I think, elsewhere. This is green

Paramœcium

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[1] Some move by means of flagella (fig. 1, p. 5).

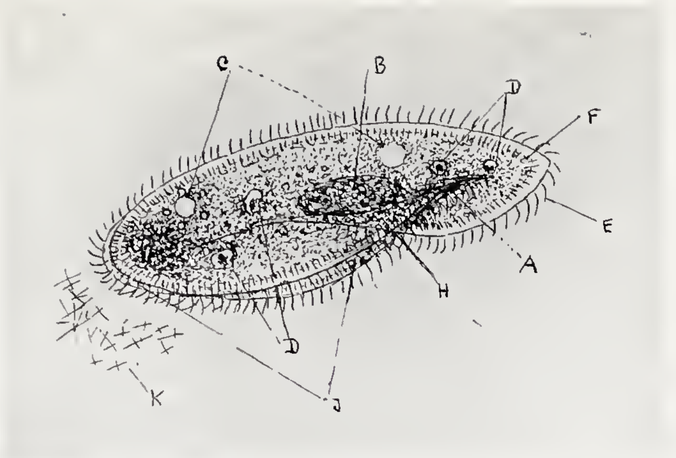

FIG. 5.—Paramœcium aurelia (× 220 diameters)—A, gullet; B, nucleus; C, contractile vacuoles; D, food in globule of water (food vacuole); E, cilia; F, trichocysts, from which long threads can be ejected, probably as weapons of offence; H, spot acting as anus; J, groove running half-way along body; K, threads discharged from trichocysts.

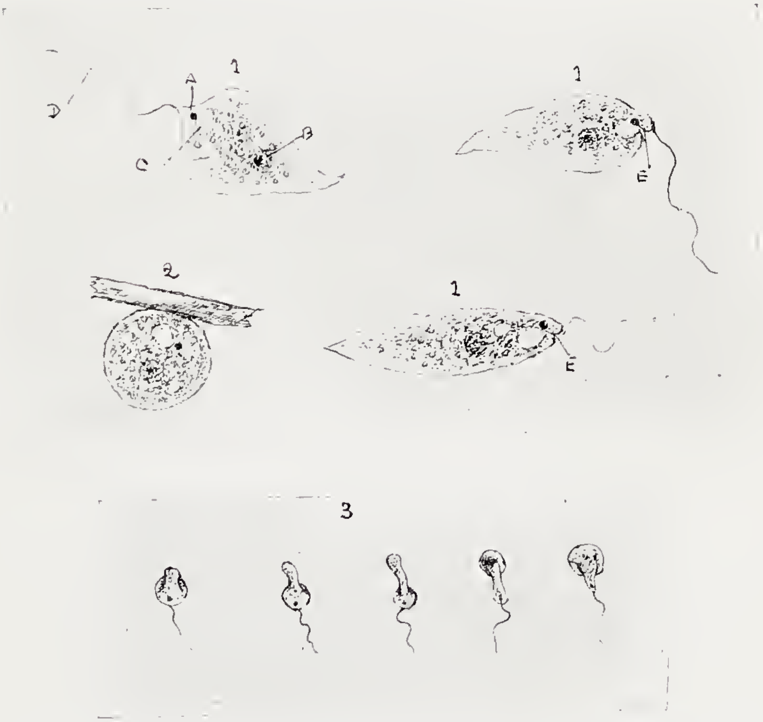

FIG. 6.—Euglena viridis (× 100 diameters)—(1) motile; (2) encysted form; (3) progression by contraction and expansion; A, red spot; B, nucleus; C, contractile vacuole; D, flagellum; E, mouth.

Facing p. 12

in colour, is provided with chlorophyll, and has therefore, presumably, the power of getting its nourishment in vegetable fashion, the power of manufacturing protoplasm from inorganic matter. But it can also, like its near relative, the Slipper Animalcule, feed after the manner of animals. Apparently, then, it is a monster, half plant, half animal. But further investigation is required before we come to this decision. Undoubtedly this Paramœcium bursaria contains chlorophyll, but it is believed that the chlorophyll belongs to minute algæ (or water weeds) which inhabit the Paramœcium. This being so, we have an instance of symbiosis or messmatism. The animal houses and keeps in its service a number of minute vegetables, the arrangement being advantageous to both parties. There is a small worm, Convoluta,[1] which is coloured green and which undoubtedly owes its colour to small algæ. They cannot, indeed, be extracted and made to lead an independent life any more than our blood corpuscles can. But two able investigators[2] managed to find the minute organism in the capsules in which Convoluta lays its eggs. Meanwhile some young Convoluta worms were being kept in sterilised water and were as yet quite colourless. When the small green algæ were introduced into the water, the Convolutas quickly assumed the normal green colour. Undoubtedly they are true algæ: they contain starch, and they have even a red "eye-spot." Is it this that enables them to find the worm that is to be their host? As to this we know nothing beyond the fact that they do somehow find him.

Symbiosis

It is a question whether all chlorophyll-containing animals are not, like Paramœcium and Convoluta, inhabited by symbiotic algæ which give them their green colour. It is possible that there may be no organism in existence which, when we judge by its diet, can be claimed both by the animal and vegetable kingdoms. But I believe that no one has yet shown that

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[1] Convoluta roscoffensis, one of the Turbellarian worms.

[2] Mr F. Keeble and Dr F. W. Gamble. See their paper on the *Infecting Organism of Convoluta roscoffensis* in the *Proc. Royal Society* (Biol. Series), Nov. 30, 1905. There is a summary in *Nature*, Nov. 30, 1905.

Euglena, an undoubted Infusorian, an undoubted animal, owes its bright green colour to symbiotic algæ (fig. 6, p. 12). Its chlorophyll, as yet, is its own, and not the property of any tenants.

Euglena

Euglena, whose turn it is now to step upon the stage, is a small Infusorian, common in ponds. By means of its flagellum it moves rapidly (appears to move rapidly when watched under the microscope), rolling over as it goes. It has also a peculiar euglenoid movement, produced by contracting first its anterior end, then its middle, then its posterior end. It is bright green in colour, and water which is thick with Euglena is found to give off oxygen. This is what all plants do in the daytime from the diatom to the cedar of Lebanon. And so, it would seem, Euglena is a plant. But close to its flagellum it has what looks like a mouth. Certainly there is a gap here in the cell wall—very unlike a vegetable this—and the cell wall itself is but a delicate skin, allowing of the peculiar euglenoid movement just described. When small particles are put in the water, they find their way in at the mouth, down the passage leading from it called the gullet, into what does duty as a stomach. No vegetable has a right to a mouth, no animal to chlorophyll. But in Euglena they are combined. The red pigment spot does not help to clear matters up. It looks like an eye, but we cannot prove that it is more sensitive to light than the general surface. The contractile vacuole must be counted as an animal point. Here is a creature more double in its nature than the ancient satyr, a man with the hoofs of a goat, a monstrous combination unknown to nature though possible to man's fancy. But in Euglena we find in combination the characters that mark the two primary divisions of organic life. It is not that the gulf between vegetable and animal is bridged by an intermediate form, but that the characters of the two co-exist.

It is a very significant fact that there is a chemical affinity, and not a very remote one, between chlorophyll and the hæmoglobin, to which the colour of the blood of the higher animals is due. Here we have evidence that plants and animals spring from a common stock. Both have specialised, but their common ancestors must have been primitive plants, not animals.

The Origin of Life

Let us consider the origin of life upon the earth. There has been much discussion upon spontaneous generation. To Lucretius, when maggots appeared in a decaying carcase, it seemed as if they had sprung from dead matter, and he moralised in his pathetic style about the decay of the earth's fertility. Earth, the mother of all,

> Omniparens eadem rerum commune sepulcrum,

formerly gave birth to great bulky animals, elephants, to wit, and others; but in his time, so effete was old Mother Earth, that she could scarcely bring forth even such things as maggots! A terrible decline indeed! In much later times people have been astonished by the fact that if flowers are left in water for a few days little infusorians appear in the water. But when careful tests were applied to see that all life was excluded, no infusorians appeared. If an infusion of grass, flowers, or any vegetable stuff was boiled, there was but little life. Still *some* live things were found sometimes, though not always, when infusions of grass or other vegetable stuff were boiled in glass tubes fitted with plugs of cotton wool to prevent the entrance of life from without. Did, then, any minute creatures survive the boiling? It turned out that some minutiæ, small infusorians, when encysted, or in the spore state, could stand even 212° F. The plan was then tried of keeping the infusion for some time in a genial temperature, so that all its inhabitants remained active, and none entrenched themselves in cysts, or (a further resource possible to many) broke up into numbers of minute spores, capable in their dormant state of resisting very great heat, and ready always, as soon as times mend, to become active infusorians once more. A very interesting account of all the experiments made to prove or disprove spontaneous generation, each designed to close some loophole through which error in the shape of a germ might possibly have penetrated, can be found in Mr Saville Kent's *Manual of the Infusoria.*[1] The evidence was complete when Mr Saville Kent found small infusorians adhering to grass and flowers growing in hayfields. The biogenists, then, who believe that all life comes from life, a modern version of William Harvey's dictum, *Omne vivum ex ovo,* have been victorious all along the line. Certainly under the conditions necessary to the experiment they have triumphed. They have proved, at the very least, that life in forms perceptible to our senses does not arise spontaneously in sterilised infusions of vegetable stuff kept in small tubes and protected from outside infection.

But now that all the fighting is over, and we are all biogenists who laugh at the idea of spontaneous generation, it must be owned that the difference is, in a sense, but the difference between tweedledum and tweedledee. We believe that life somehow originated on the earth. There was a time when the earth was in a state of fluid heat, and living organisms such as we are familiar with could not exist there. As the earth cooled, life appeared. To suppose that it came with meteoric stones falling upon the earth is only a temporary makeshift of an explanation. How did it originate elsewhere? We come back to this, then, that life must have originated from lifeless matter. Still, living organisms, such as we see, even the smallest that the microscope can detect when it multiplies lengths and breadths 15,000 times, spring from living organisms like to themselves. But below these smallest of known forms of life must be others smaller still, indiscernible to the human eye, even when its keen edge is made keener by the microscope, some half-way house between the inorganic and the organic, some upward step towards those cells of protoplasm of which all living things are built. Such unrecognisable rudiments of life may still be arising. If so, it is quite possible that they all die out before they have been long in being, since earth, water, and air are crowded with organisms that evolution has lifted to a higher level. Some restatement, then, is wanted of the proposition, "All life springs from life."

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[1] Vol. i. pp. 118-142.

Qualifying it, we can say, without fear of refutation, " All living things *that we know* spring from living things," and we may add, " from living things not unlike themselves."

Priority of Plants

Thus much being settled, let us now go on to a much simpler question: Which can claim priority, the vegetable or the animal? This need not detain us long. The vegetable requires only inorganic food; the animal depends on other lives for his life. The tiger and the other carnivora are supported indirectly by plants, for their victims (or at any rate their victims' victims) are vegetarians. The plant, therefore, must have been first in the field. As soon as the earth became cool enough, all the circumstances were favourable for it. There was soil formed from disintegrated rocks, there was water, there was air, there was sunlight—ether waves bringing light and warmth, and energy too, if only the chlorophyll (indispensable requisite) was there to turn it to use. So for plants there was a suitable environment (to use a favourite modern word meaning all the surroundings and conditions) when the earth was as yet for animals an uninhabitable desert.

Consider now what kind of plants those that were made by the "'prentice hand" of Nature must have been. Certainly they were not like our monarchs of the forest. No, it was a time of small things so far as life was concerned. The earliest plants, we can confidently assume, were single cells of protoplasm. If their home was the water (and very probably this was the habitat of the most primitive) they would float with currents or be driven by the winds that crisped the surface of their pools or lakes or seas. But if they drifted with every current, like a log upon the sea, they might find themselves in uncongenial places—on the bank, for instance, and roasted to death by the sun. Hence some swimming power would be necessary, or at least advantageous, and in the living world it is found that the powers which are necessary to life, somehow, however we may account for it, come into being in the course of generations, and those that are possessed of these powers survive and prosper.

Hence we may believe that Protococcus represents, as far as its powers of movement are concerned, a very early type of plant. Take another very simple type, the Diatom. Its microscopic steps or rather slides probably, as I said above, save it from getting covered with earth and the débris that deposits itself at the bottom of its pond.

We imagine, then, the primitive vegetable, the manufacturer of protoplasm, moving about, though but slowly. But animals, Nature's nobler work, have, so to put it, said to themselves, Why do work of supererogation? Why do what you can get some one else to do for you? (A fine definition this of work of supererogation, found in *Punch* years ago.) And thus there arose among primitive organisms some which did not manufacture protoplasm for themselves, but, devouring their neighbours, obtained it ready made. It required something of a mouth to carry out the new plan, but not much beyond this. Here, then, is the animal arising from the vegetable, an advance great in itself and pregnant with great possibilities. No doubt the change seldom came all at a bound. There must have been a time when the half and half stage was common, when there were many organisms to be found that belonged partly to one category, partly to the other. Of this class there still remain some, the plague of those naturalists who worry over such things, the delight of those who see in them a vestige of a transition period long past.

Ambiguous Organisms

There is no better or more familiar example of the half-way house in the process of evolution from plant to animal than The Springing Monad Heteromita, the Springing Monad.[1] Specimens are easy to get. If flowers are left for some days in water, live things are always to be found in it, and often among them is Heteromita. It appears also among decaying animal matter. I have found it swarming among the eggs of unhealthy sea-urchins. It is very minute, about $\frac{1}{3000}$ of an inch in length, and moves by means of two flagella. Often it anchors by one of them, and by coiling and uncoiling the other springs forward and retreats. Its

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[1] Fig. 7, p. 19.

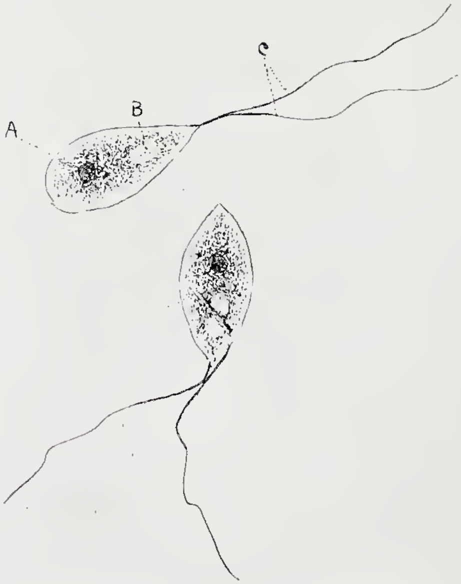

FIG. 7.—Heteromita, the Springing Monad (× 1000 diameters)—A, nucleus; B, contractile vacuole; C, flagella.

Facing p. 19

cell wall is a very delicate skin and does not consist of cellulose. It multiplies by fission. Conjugation also takes place, and from the fusion results an organism of triangular shape, which discharges thousands of spores, each to become in time, if there is no accident, a Heteromita. Nutrition is saprophytic: decaying matter is absorbed through the thin cuticle. Thus it does not like a true animal first break up and make diffusible the protoplasm which it feeds upon, then build it up into its own substance. It takes protoplasm that is already in a diffusible state and at once begins the constructive process. On the other hand, it does not, like a true plant, take inorganic matter as its food. It is, therefore, in strictness neither plant nor animal. It cannot do the work of a plant, the primary work on which life depends: it cannot convert inorganic matter into protoplasm. On the other hand, it does not feed as a true animal feeds.

Take another example, Mucor, the mould which forms on the top of jam or in damp bread when the air is not allowed to get to it (fig. 8, p. 20). It consists of a number of aerial hyphæ, as they are called, each a long cell with a number of nuclei. Each is one long cell till a sporangium (a case full of spores) forms at the top. Then a septum divides the sporangium from the rest of the hypha, and thus there are two cells instead of one. Sometimes the hyphæ send out branches. When two branches meet, a separate cell forms at the end of each and conjugation takes place. The cells have walls of cellulose, and nutrition is generally saprophytic; Mucor lives on decomposing organic matter. The solution, whether it be the artificial solution named after Pasteur or derived from jam or manure, soaks through the cell walls and is then built up into the organism. When Mucor grows on bread its method of taking nourishment is said to be almost holozoic, *i.e.* it feeds almost as an animal. I have not been able to see the process, and I do not understand how with its cellulose wall it can take solid food. But in any case it seems wrong to reckon Mucor, as all authorities do, definitely and absolutely a plant. It has lost the most crucial diagnostic character of a plant: it cannot live on inorganic food. **Mucor**

As to the cellulose which forms the walls of its cells, the Ascidians (see p. 26), undoubted animals, live in an envelope of cellulose, so that we must count that a minor point. Like Heteromita, Mucor has set out to become an animal and has only travelled half the distance or, in my opinion, a good two-thirds of the distance to be traversed. Though it has travelled so far, all authorities rank it as a plant. There is a feeling that such a thing as mould should not be in the main an animal. What we call common sense revolts against it. But the scientific mind, of course, does not allow an appeal to feeling or common sense. And so it takes cover in this case behind the cellulose wall (very poor cover that !), whereas the real question to ask is : Does the organism live on organic food or inorganic ? Test it in this way and we see that Mucor has abandoned the vegetative mode of life and gone far to become an animal. It has stopped short, since it does not swallow its food in gobbets by means of a mouth, but absorbs it through its cell walls. With regard to Bacteria our verdict must be the same. Commonly classed as vegetables, they are really, in the main, judged by their diet (which is the great test), animals. What is inorganic cannot serve their turn. They live like Mucor and Heteromita on putrefying organic matter.

Bacteria

This settled, or settled as far as may be, we can leave Heteromita, Mucor, and the Bacteria, and pass on to other matters.

Insectivorous Plants

Some organisms that are clearly and unmistakably plants have adopted an animal habit of life. The Bladderwort catches water-fleas. They can be seen moving about within the bladder, unconscious that they, the higher organism, are going to serve as food for the lower. The Pitcher Plants catch insects, and thus supplement their vegetable diet. But the most celebrated of all the animal-eating plants is Drosera, the fly-catching Sundew, to which Darwin devoted so much study (fig. 9, p. 21).

The Bladderwort

The Pitcher Plant

The Sundew

There is no reason to be surprised at plants adopting animal ways. They want protoplasm. If they manufacture it for themselves out of inorganic materials, they are living as plants

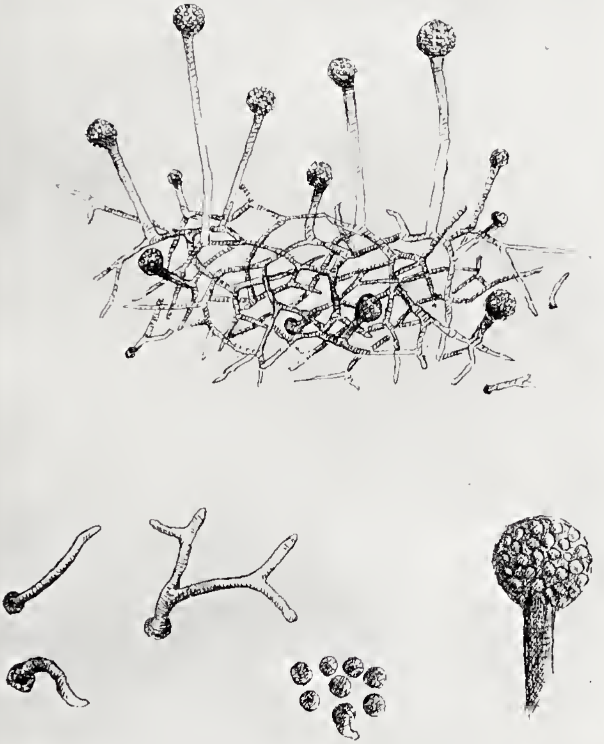

Fig. 8.—Mucor. Upper figure × 250 diameters, the lower 350. The aerial hyphæ carry the sporangia. Below, a sporangium, separate spores and, on the left, spores germinating.

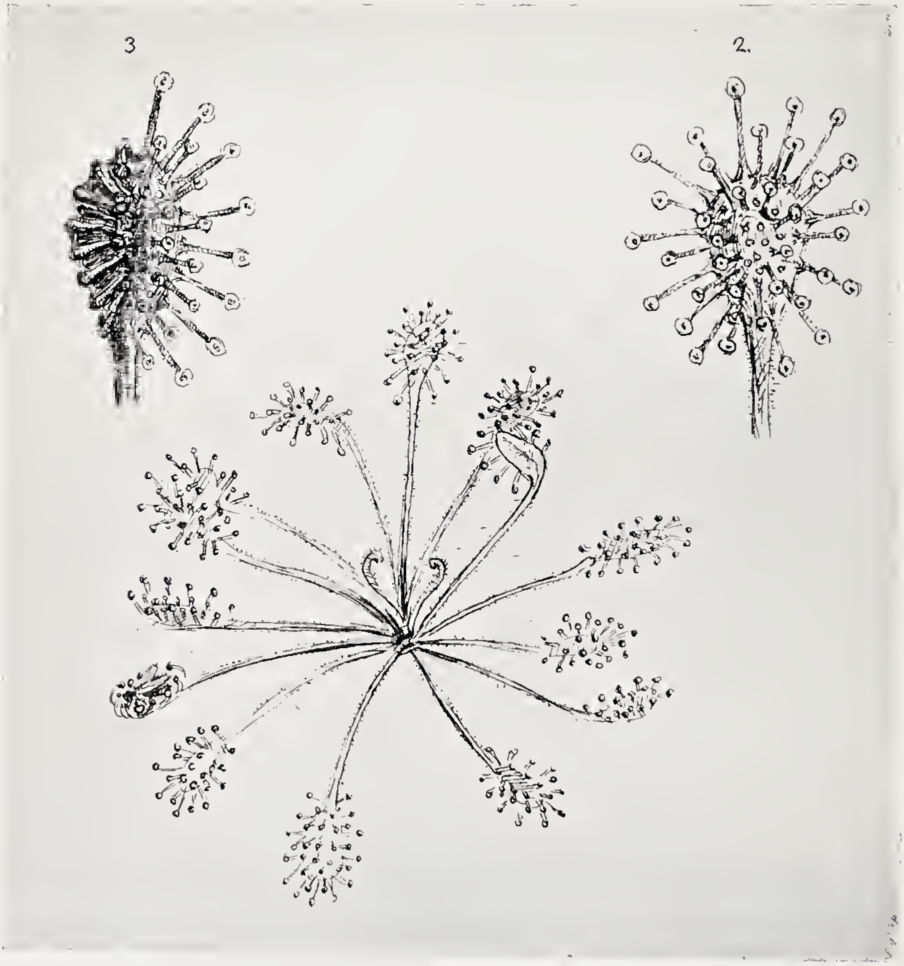

FIG. 9.—Sundew, Drosera anglica, life size. Fly being digested by leaf on left. (2) and (3) leaves enlarged; (3) showing flexion of tentacles.

Facing p. 21

live. If, on the other hand, they were to get it ready-made, they would be living after the manner of animals, and would be in fact (except for the minor question of a cellulose wall for their cells) animals. But those with which we are now concerned only in part adopt an animal mode of life, and remain in other respects vegetables, and therefore we speak of them as plants, though with curious unplant-like ways. If a plant were to go the whole hog and entirely give up its inorganic diet as well as its vegetable method of growth and reproduction, we should rightly call it an animal, disregarding its origin and looking only to its adopted habit of life. Indeed, it is in this way that animals must have sprung from plants.

Some further account now of the Sundew. The Sundew catches flies and digests them. Its leaves are covered with tentacles and at the end of each tentacle is a gland. When anything alive or dead, organic or inorganic, is allowed to rest on any of these glands, the neighbouring tentacles bend towards it. If it turns out to be inedible, they soon straighten out again. If it is a fly or a bit of meat they concentrate themselves upon it, they digest it by pouring upon it their acid secretion, similar probably to our gastric juice, and do not rest till they have absorbed all that is nutritious. "A tentacle with a bit of raw meat on the gland has been seen to begin bending in ten seconds, to be strongly incurved in five minutes, and to reach the centre of the leaf in half an hour."[1] The sensitiveness of the tentacles is almost incredibly delicate. Darwin found that a tiny piece of thread, weighing $\frac{1}{8197}$ of a grain, put on a gland caused the stalk of the tentacle to bend at its base, a motor impulse being transmitted through the whole length of the pedicel consisting of about 20 cells. And yet drops of rain do not cause it to move. It is remarkable, too, that the nerve thrills as they pass from tentacle to tentacle, seem to follow certain lines, vaguely suggestive of nerves, to travel more rapidly along the leaf longitudinally —from the middle towards the tip or the base—than from the middle to the sides. Here is another thing that must make one think of the Sundew with respect: a tentacle, if a piece of meat is placed on it, bends towards the centre. But if several tentacles near the edge have meat placed on them, their neighbours bend, not towards the centre, but towards the meat. If the movements of the tentacles are merely due to chemical reaction, are merely automatic, yet there is a wonderful method about their automatism, a wonderful simulation of intelligence.

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[1] Darwin's *Insectivorous Plants*, p. 262.

To sum up, the Sundew catches flies, eats and digests them. It shows a wonderful sensitiveness, suggestive of nerves. But we must put it down as a vegetable. Its leaves contain chlorophyll; they take in carbonic acid gas and break it up into carbon and oxygen as only a true plant can. This settles the matter. Besides this, it has the roots of a plant; as a true plant, it flowers and reproduces itself. But the Sundew has adopted animal ways—it is a hunter, though a fixed one—and these animal ways enable it to live in very poor soil or among moss. As a plant it lives hard, as an animal it is a sybarite.

Things common to Plants and Animals

We must now leave such ambiguous organisms as Heteromita, Mucor, Drosera behind us. Most organisms throw in their lot definitely with one party or the other, and the different nature of their food has led them along different lines of development. In one point, however, the higher forms of each are alike. When fission takes place, the two cells that result from one do not, as in the case of the unicellular organism, part company, but remain adhering to one another. And by this means a big organism is built up. Moreover, alike in the higher plant and the higher animal, specialisation of cells goes far, though much farther in the latter. In the oak you have special cells in the root, in the stem, and in the leaves, to say nothing of the flowers and fruit. In the rabbit you have specialisation producing nerves, muscles, bone, skin, and hair, and so forth.

Mobility

Then there was the question of mobility or fixity, a question which arose in early days and had to be decided. Plants and animals, by a huge majority in each case, have settled this question differently. The question was: "Is it better to live anchored to one place, or to live a life of movement and travel?" Now, a plant can find food in most places. The atmosphere envelopes the whole earth, and everywhere except to far-stretching caves and the depths of the sea the sunlight penetrates. The sun and the wind play over the plant's enormous surface of green leafage, a breathing and feeding surface both in one. Soil is wanted, and for that no travelling is necessary. The plant itself renews it to some extent by the shedding of its own leaves, and fresh soil is perpetually being formed through disintegration of the rock beneath by water, the great destroyer, aided often by the acids given off by the plants. There remains the question of a continuous supply of water. Leave a cut flower without water and it very soon droops. A growing plant is little better off if its water supply entirely fails. But against this it guards by sending its roots deep into the ground — wheat often some six feet or more. Desert plants have roots of an extraordinary length. In the north of the Sahara, where drought continues almost throughout the year and a storm that fills the dry watercourses is a rare event, the long roots of the very small bushes, many times the length of the bushes they nourish, can be seen exposed at the side of the dry river beds, where the short-lived torrent has cut its way into the soil. Thus air, water, soil, the plant can have without moving. It settles down, therefore, to a sedentary life, and, instead of going in search of food, finds it ready to hand, and is ministered to by earth, air, and water, only having to stretch forth its vegetable hands to take what is offered it; a lazy life, but not a few men who can afford to keep many servants to wait upon them tend to adopt habits that are not very different.

Longevity of trees.

Certainly this is a life that is favourable to longevity. In the British Museum at S. Kensington is a section of a pine tree from Canada on which 500 rings and more may be counted. Here and there on the rings are recorded events in English history which took place while that particular ring was growing. But a tree of 500 years is a mere chicken if it be one of a long-lived sort. There is also in the British Museum a section of a Sequoia tree from California which had seen over 1300 summers before the saw laid it low. Never in all these centuries had soil, water, or air failed it. And, what is perhaps more extraordinary, there had been no forest fire to reduce it to ashes! Men, the reckless destroyers of the slow-growing wealth of timber, had been there for centuries and no chance spark had set going a conflagration to tame this giant Sequoia. Apart from man, there are fires started by volcanoes, lightning, heaps of damp decaying vegetation. But these 1300 years had passed there without a conflagration due to man's carelessness, or the blind forces of nature.

When vegetables emerged from the water and made their home on land, it was inevitable that they should give up their power of moving from place to place. Even of those that remained water plants, many have cast anchor. Very probably after developing as land plants they have returned to their former homes and now, larger and stronger than of old, have rooted themselves firmly. The proverb says, "Everything comes to those that wait." For plants it is a proverb of almost universal application. An animal must apply it with judgment on carefully selected occasions only.

Activity of animals

Animals, whether they remained in the water or came out on to the land, were bound to lead a life of activity—with certain exceptions which I shall speak of soon. If they are vegetable feeders they soon exhaust the food in one place. If they are carnivorous, their food requires catching. It is a not uncommon thing now to see cows tethered in grass or clover fields. An economical plan! The cow eats every morsel of green stuff that comes within her reach. Revolving within her fixed radius she very soon clears her allotted circle completely. What if she were so tied for life? Her span of life would be but short. All the grass-eaters, leaf-eaters, fruit-eaters, have to travel in search of new pastures, new crops. Even the life of the vegetarian animal is one of restless activity, compared, that is, with the life of any plant.

Still less can the carnivora live a sedentary life. Not only have they to travel in search of food, but to catch it when they find it. The hunted, the ruminants, have developed a swiftness of foot to rival that of their pursuers. What need for the

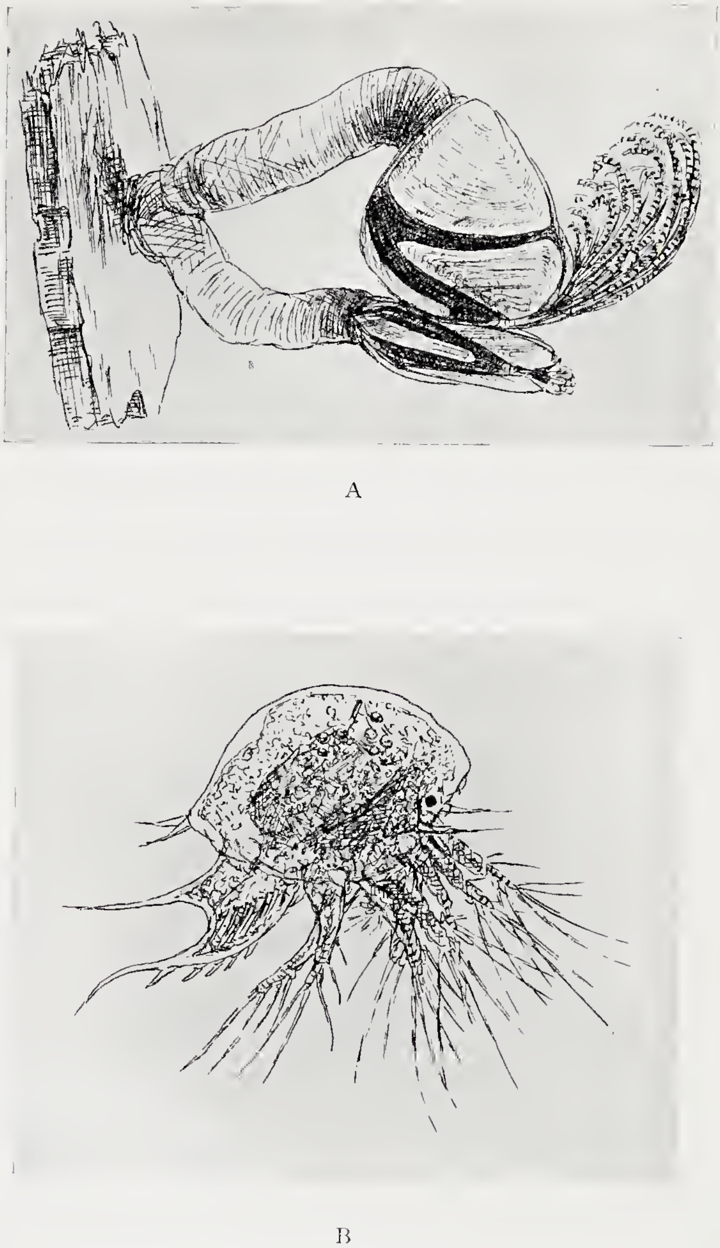

FIG. 10.—A, stalked barnacles ; B, free-swimming (nauplius) phase of sessile barnacle. It swims by spreading all its appendages, then drawing them together so as to drive out the water. It is just visible to the naked eye.

Facing p. 25

antelope of his wild speed if there were no lion to surprise him and pursue him? The cheetah would not have the speed of a greyhound if the deer and the antelope could be caught by the slow of foot; as soon as animal mobility originated through the necessity of going in search of food, it was inevitable that it should develop further. The plant-eater might become a hunter and animal-eater, for the protoplasm of vegetable and animal is essentially the same. Hence, for many, speed of foot was the all important thing, and there were races in which life was the winner's prize, and death the penalty of the vanquished. No doubt it may seem heartless and cruel, the tiger catching and devouring the deer, the falcon swooping on the jackdaw, or even the cormorant hunting down the fish. Nevertheless, we owe to the beasts and birds that hunt and kill, the speed and energy and much of the grace of the animal world. Except in some quiet corners, the earth (the land, I mean) is no place for animals that are dull and lazy and torpid. For plants a sluggish vegetable constitution! They stand for torpidity. Patience is their virtue and they wait for their food to come to them, just as we expect to find air to breathe wherever we go. The animals stand for the restless life, the frequent replacing of worn-out protoplasm by new (except for the recurrent periods of torpor, short periods in most of the higher species[1]), the continual hunt for food or toil to produce it. But there are animals for whom circumstances have made possible a life of vegetable torpidity. They are especially common in the sea. The flow and ebb of the tides bring with them large supplies of minute life, hosts of floating diatoms and other minute algæ, tiny crustaceans, the marine relations of the water-fleas and cyclops of our ponds. Every rock on many coasts is coated over with barnacles, and these barnacles, these anchored crustaceans, are sprung from ancestors who were capable of locomotion, crawled or swam and were worthy of the name of animals. Now, their heads fixed on the rocks, or the stalked forms on timber, they play about with legs in the water and kick what food they can into their mouths

Sedentary animals

The Barnacle

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[1] I should have mentioned here the mammals that hibernate: in Britain the Dormouse, Squirrel, Bat, Hedgehog.

(fig. 10, p. 25). At low tides may be found numbers of light brownish seaweed-like growths on rocks—always taken by the uninstructed for seaweeds—which in reality are animals that have adopted a sedentary mode of life. They are called Hydroids because of their kinship to the little hydras of our ponds. They live pedestalled upon rocks or shells or seaweeds—each is a colony of animals living in a community together. The heads or zooids look like little sea-anemones, and they are, indeed, near allies of the sea-anemone. Each head has a ring of tentacles armed with tiny poisonous darts. With these weapons it is able to kill many small victims. Then the booty is drawn into the mouth at the centre. Certain of the zooids separate off and the buds start an independent life on their own account—a very plant-like mode of reproduction. For a time they lead an active life. They are, indeed, in many species, little Medusæ or jelly-fish, swimming by alternately closing and opening the umbrella. They develop eggs from which, when fertilised, spring zooids which cast anchor, grow into plant-like colonies, and so complete the cycle of life. Thus there are alternating generations, the free-swimming jelly-fish and the plant-like colony, once called a zoophyte, an animal plant. And indeed, though it feeds like a beast, it has been de-animalised in one important respect. It no longer hunts for its food, but waits for tides and currents to bring it. Tubularia is one of the handsomest of hydroids (fig. 11, p. 26). In Tubularia the free-swimming Medusa stage is suppressed. The Medusæ are indeed formed, but they remain as buds adherent to the parent stem. Like the free-swimming forms of the species they carry on the process of reproduction and give birth to Actinulæ, as they are called, which, after floating about for a time, anchor to a rock or to an old-established Tubularia colony, and grow and branch and produce a number of zooid-heads. In the illustration an old colony is shown with young ones growing up it.

The Hydroid

Much higher in the scale we find degraded animals, no longer hunters, but mere trappers or, more properly, traps. The Sea-squirt,[1] so called with something of contempt, has a wonderful

The Sea-squirt.

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[1] Scientifically Tunicate or Ascidian.

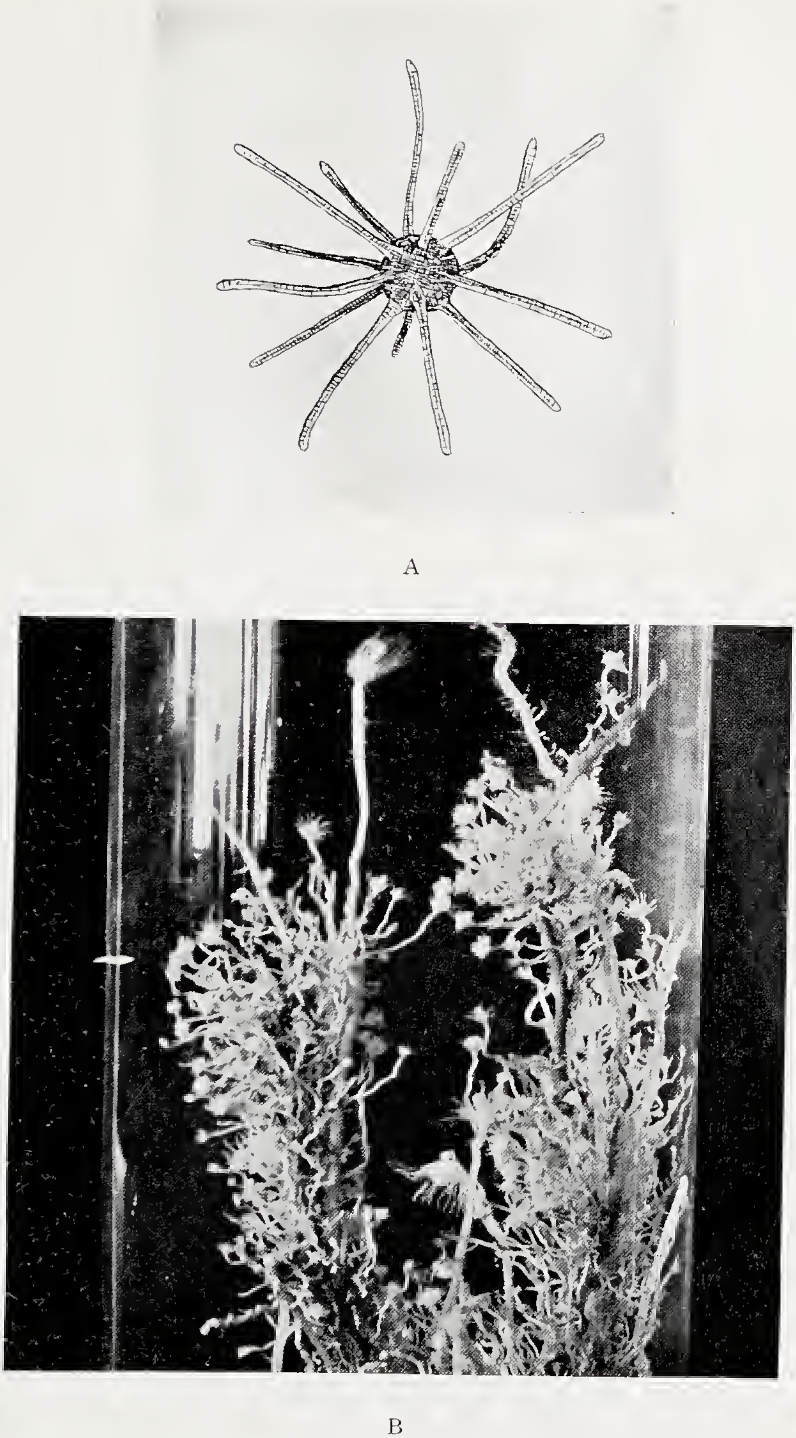

FIG. 11.—Tubulari aindivisa—A, floating crawling phase (magnified); B, as a fixed hydroid, young colonies climbing up an old one (height, 10 inches). The latter has large zooid-heads.

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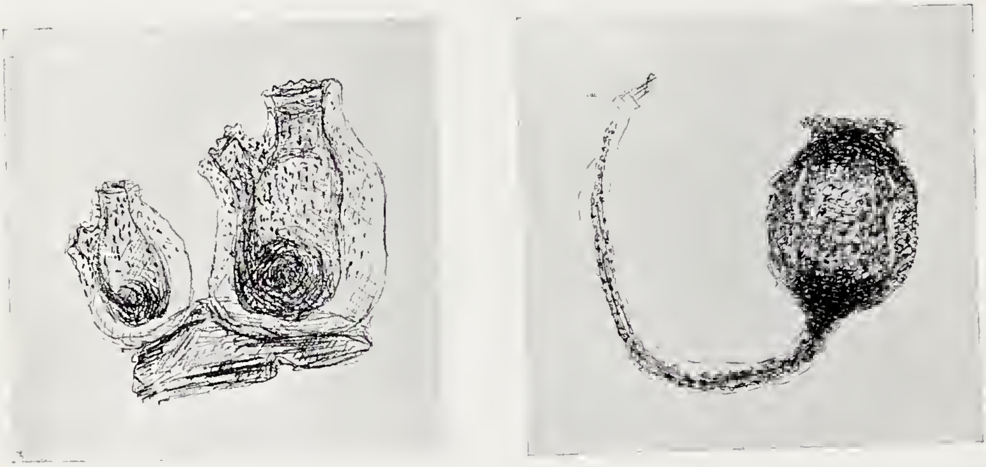

A (about natural size). B (much magnified).

FIG. 12.—Sea-squirt—A, ascidia virginea ; B, tailed larval stage of Polycarpa glomerata.

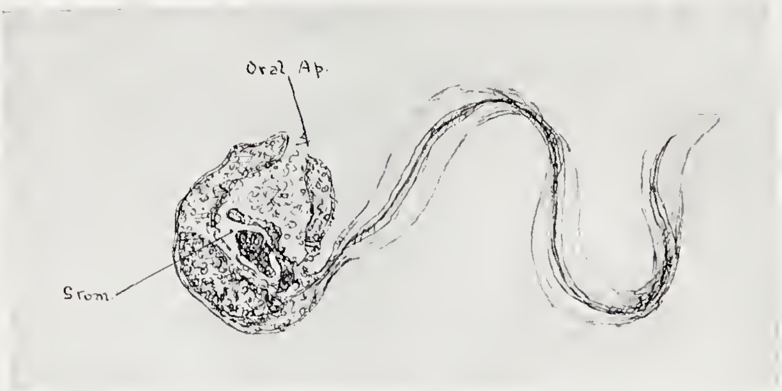

FIG. 13.—Oikopleura, a tailed free-swimming Tunicate (Sea-squirt), easily distinguishable under a magnifying glass. It retains its notochord throughout life. Stom, stomach ; Oral Ap, oral aperture.

Facing p. 27

life history. One kind, called "red currants" from their colour and appearance, sometimes coat the walls of sea caves. Try to pluck these "currants" and their watery contents squirt out in your face. Each is a double bag. He has an inhalent aperture through which cilia, very minute hairs, sweep a current of water into the inner bag (fig. 12, p. 27). Through little slits it passes, close to the blood-vessels all the while, into the outer bag, and is driven from the exhalent aperture into the sea. As it goes it supplies our sea-squirt with oxygen and the process of breathing is accomplished. A special line of cilia, with heads sticky with mucus, lay hold of whatever live minutiæ are in the water and take them to his mouth. So the current of water brings both food and oxygen. No need to go in search of prey.

The heart of the sea-squirt is a long bag, and when a small transparent specimen is put in a little tank of water, with the help of the microscope the beating of the heart may be clearly seen. For a long time the blood is driven, say, to the left; then the heart pauses and it seems as if the animal were dead; then it seems to revive. The pulsations begin again, but now in the opposite direction, to the right. What a staggering sight this for the man who first discovered it! Even later observers who are told that this is a thing to look for cannot see it without astonishment. The periods are generally more or less regular, so many minutes to the left, so many to the right. If the water is not fresh they seem to last longer. One I watched beat 9½ minutes one way, then 9½ the other. In another sea-squirt (in, I think, fresher water) the periods were 6½ and 5½ minutes, approximating to regularity. Another changed direction after varying times, 2½, 6½, and 4½ minutes. The pulse was a little over 40 per minute. I have been assured that if the table on which the sea-squirt in his little tank of water is resting is thumped and shaken the direction of the heart's pulsation is changed, but when I have thumped the table, no change has occurred.

The sea-squirt is enclosed in a thick coating of cellulose, the substance of which the walls of plant cells are made. In compound sea-squirts that live grouped round a centre, each with a mouth of its own, but with a common outlet from their alimentary canals, buds are thrown off (a highly vegetable proceeding), and these in time settle down to the life of sea-squirts. But the form of propagation common to sea-squirts that live as individuals, and also to those that are compound, is by means of eggs that begin to develop within the outer bag of the mother. From there they are ejected into the water, and when those sea-squirts that we called red currants are put in a pie-dish, little red specks can be seen at the bottom, and, as you look, some are moving! And they have tails! (fig. 12, p. 27). And this fact is the opening chapter of a wonderful story. In this tail can be made out a notochord, in other words a rudimentary backbone. Think of the delight and pride of the man who first made this discovery—that the ignoble sea-squirt, type of animal degradation, could lay claim to belong to the class chordata, and thus be the near ally of the vertebrates among which man himself is the pre-eminent figure. Some of these sea-squirts throughout life retain a tail in which the notochord can be seen. Drag a tow-net behind a boat and Oikopleura (fig. 13, p. 27) can often be caught in numbers, or that still more beautiful form Fritillaria. There is the notochord, part of it, persisting. But a backbone should culminate in a brain. And in sea-squirts nothing but one solitary nerve-ganglion can be made out (it lies between the inhalent and exhalent apertures). For a sea-squirt a brain would be a superfluity.

Let us now take a rapid survey of the common sea-squirt, what he is and what he was. He is enclosed like a mere vegetable cell in a coating of cellulose. The compound forms throw off buds, though they also propagate by means of eggs and sperms. In mature life they remain anchored to rocks, sweeping small animalcules into their gullet by means of cilia. Once they owned a notochord and were on the up-grade on the way to become vertebrates. Except in Oikopleura and a few others, this notochord survives only during the embryo stages. And for brain only one solitary nerve-ganglion instead of a long nerve chain culminating in a brain. Here is degradation indeed! How are the mighty fallen! Here is the most melancholy subject that poets have found to sing of—the debasement of what promised to be noble! Hopes ending in decline and disenchantment!

We have now investigated three forms of animal life that have become sedentary and plant-like in their habits during one phase of their life-cycle—the barnacles, the hydroids, the sea-squirts or tunicates (so called because they live in a jerkin of cellulose). How has this degeneration been possible for them? It must, of course, be due to some peculiarity in their environment. Such a thing does not occur on land, it is rare in ponds, lakes, and streams. It is mostly marine animals that adopt a sedentary life. The sea encourages such an existence. Twice every day the tide sweeps in, bringing with the flood of waters a flood of minute animal and vegetable organisms that form the diet of the fixtures we are considering. As plants anchor for life because their food is at hand in the soil or comes to them in the air, so the barnacle, plant-like, builds himself onto a rock because movement would be superfluous. The tide saves him the trouble of moving. Why should he go hunting when the game will come to his door? Small crustaceans (the entomostraca) swarm in the sea and the hydroids lay hold of them. The sea-squirts sweep in microscopic plants or animalcules, mere kickshaws, but kickshaws in myriads. The vast expanse of ocean is the breeding-place of hosts of microscopic things, which tides or other dependable currents carry to the open mouths of the animals which coat the rocks wherever the seaweeds will make room for them. It is a more dignified life than that of the mere parasite who makes his home in another animal and preys upon him. Still, as I have said, they are mere traps rather than hunters properly so called.

Many species of marine animals require clear water to live in as well as regular supplies of food. The clearness of the sea is one of its most striking characteristics. Though the tide carries with it a good deal of sand or mud from the shore, yet when it pauses at the ebb all this sinks to the bottom, and the tide returns clear but teeming with life. In the Mediterranean where there is a tidal rise and fall of not more than a foot or so, there seem to be nevertheless regular currents which keep up the sedentary forms of animal life. An Englishman, when he stands on the shore of the Mediterranean, cannot help noticing that there are no seaweeds, no animal fixtures in the shallow water just close to the shore. But a little way out, presumably encouraged by regular currents, there is a rich fauna of this kind (hydroids, sea-squirts, polyzoa, etc.), and, I believe, a fair show of seaweeds. A good example of the work of a dependable current is to be seen in the narrow channel between the Isle of Man and the little island to the south of it called the Calf. If you go there when there is a good low tide (a drop of some 20 feet, that is), you find every broad ribbon of the laminaria seaweed overgrown with small hydroids, the rocks in places covered with forests of Tubularia, sometimes growing to a height of ten inches, sea urchins in numbers, sponges showing their green and yellow colours, compound tunicates (sea-squirts), dead men's toes (somewhat repulsive name for a beautiful creature), and most beautiful of all, hundreds of sea-anemones looking like roses just below the surface of the water. Through the channel where all this is to be seen, there is always a strong tide sweeping. Hence the wonderful richness of the fauna.

Sedentary fresh-water animals

In fresh water the circumstances are less favourable to sedentary animals. It is true there is often a great deal of microscopic life. In small ponds, entomostraca (small crustaceans), rotifers, infusorians, small algæ (fresh-water seaweeds, if I may make a bull), are found in abundance. In the Norfolk Broads the number and the variety of the entomostraca is astonishing. In rivers there is much less life of this kind, since the current would carry away such helpless small fry to a death in salt water.[1] But why with all this abundant food supply in the Norfolk Broads, for instance, are there no hydroids, no barnacles, no fresh-water representatives of the sea-squirts, but few sponges, and few polyzoa? True, there is one hydroid in Hickling Broad, growing on the reeds, a little below the surface of the water. Only one species and that growing in one place only. There is evidently something unfavourable in fresh water to animal fixtures. In Lake Tanganyika (and, I believe, in Victoria Nyanza) there is a species of jelly-fish. It lives and thrives in fresh water, so much so that Tanganyika swarms with jelly-fish in June and July. But—a very significant fact—there is, as far as our present knowledge goes, no hydroid stage. The animal is mobile throughout its life cycle. In lakes and ponds there are no tides and no regular currents to bring a daily supply of food to the animal who merely sits and waits for his meals. Moreover, there is much dirt in the water of most ponds and of the Norfolk Broads, the débris of water plants. Lakes are sometimes almost free from dirt; but they are, as far as my experience goes, not rich in microscopic life—why, I don't know.[1] Moreover, the bottom of a pond or a mere affords but poor anchorage, being either nothing but mud or else overgrown with plants. Altogether the conditions in fresh water do not encourage animals to give up their mobility.

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[1] Certainly in all but the most sluggish streams.

A Species cannot be sedentary though an Individual may

However, it would be fatal to any species, whether plant or animal, if the individuals composing it lived their whole lives through in one place and never moved house. The individual, during part of his life cycle, may find circumstances that make all travelling, all hunting for food, mere waste of energy. The species must travel or perish. Hydroid, barnacle, sea-squirt, herb, shrub, and tree, are liable to accidents. Some diversion of an ocean current, a sudden influx of enemies, some period of drought on land, some change of temperature, may prove fatal to a whole neighbourhood of sedentary animals or plants. Hence the species must be always at work extending its range. If it is limited to some few square miles it is on the verge of extinction. To travel, therefore, is necessary for the species, however long the individual may bide at home. And so plants have all manner of contrivances for getting their seeds transplanted to new lands—the locks and keys of the sycamore, the tassels of the hornbeam, the thistle down and hundreds of others for the wind to whirl along. That little gourd, the colocynth, loaded with its highly medicinal pips, goes bowling about the Sahara when there is a hurricane blowing. The bur, the nut, the strawberry, and the many other esculent fruits have but one *raison d'être.* They bring it about that beasts and birds become bearers of seeds, so that new territory is added to the habitat of the species that produces the hooked tenacious bur or the tempting fruit.

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[1] Probably for want of regular currents.

These things are all familiar. But not everyone knows that the barnacle in early life swims freely in the seas (fig. 10, p. 25), till at length his travelling days are over and he fixes his head upon a rock, and loses his eyes, while his tentacles leave barely traceable vestiges. Not every one knows that the tunicate has a tail and can swim, till he finds what is the one place for him, loses his notochord and his activity, and, forgetful of his kinship with the vertebrates, becomes a mere sea-squirt. Not every one knows that the hydroid, too, has its mobile stage—how many people have ever heard of a hydroid?—that it swims when young in the familiar fashion as a jelly-fish or, at the worst, crawls along the bottom. Thus the sedentary animals have not entirely resigned their animal activity. They have their mobile period, during which they seek out stations for themselves. The plant, on the other hand, gets itself transplanted by beast or bird or wind. There has been in its case a more complete abdication, a more complete loss of primitive mobility than we find in the case of the sedentary animals. Among the latter there breaks out in youth, or in parts of their life cycle, the true animal restlessness.

Plant and animal are what they are very largely because of the nature of their food. Wanting only inorganic nourishment the plant waits patiently and, without moving, gets its supplies of soil and water and air. The animal, save only when circumstances are exceptional, goes out foraging or goes out hunting, a more active kind of foraging. The carnivorous habit arose—must have arisen—before animals had existed long. If protoplasm was to be the diet, why abjure animal protoplasm? Hence nearly all animals must hunt or be hunted. Many of them figure in both capacities. In the present chapter we have been concerned with animals that have become trappers or mere traps, rather than hunters properly so called.

Chapter II

THE SEA AND ITS INHABITANTS

The Sun the Source of Life

Wherever our sea-coast has rocks to show, they are covered, as far up as an ordinary tide rises, with seaweeds or limpets or barnacles. The plants and the animals jostle for places on the rocks, and it is often difficult to make out why sometimes the one class triumphs, sometimes the other. For both of them the rocks serve only as pedestals. No roots are sent out by the seaweeds, but they anchor firmly, and yet often drag their anchors in time of storm.

The surface waters teem with minute life, both vegetable and animal, the floating flora and fauna, which, though many of the representatives of the latter swim with vigour, yet travel mainly with tides and currents.

Sea caves

Suppose, now, we inspect some ocean caves. Recently I have visited some in the Isle of Man, between Port St Mary and the Calf Island. The walls up to an ordinary high-tide mark are covered thick with barnacles (the highest parts are monopolised by them), by the red ascidians or sea-squirts, the "red currants" before mentioned, by big grey sponges, by smaller green and yellow sponges, by hydroids (see p. 26), with an occasional nudibranch (a sort of mollusc with its gills uncovered), and numbers of sea anemones, collapsed and unsightly if left bare by an unusually low tide—and only with the help of a good spring tide can one get into the caves—but beautiful as roses if just below the surface and expanded. Among all this wealth of life there is not a single plant. Small floating algæ flock in with the tide, but they come in as visitors only. Among the regular residents of the caves there are no plants.

On the rocks outside there is the usual fight for places, barnacles mainly representing the animals versus the seaweeds. Here in the caves the plants abdicate and leave the field open for the animals.

It is easy to find the explanation. There is not enough light for a plant to live and thrive. But animals can live in these dimly-lit halls. Their food floats in twice daily with the tides. What more do they want?

But plants crave for sunlight, and without it pine and die. Indeed, all life and energy upon our planet is traceable to the sun. In coal is stored some of the sun's radiant energy, won and turned to use by plants that lived long æons back. We speak of candle-light, lamp-light, and so forth. But indirectly the light comes from the sun.

Chlorophyll

It is only plants possessed of chlorophyll (the substance that gives the ordinary plant its green, that gives the seaweed its red or green, or more often its brown) that can make the sun's energy their own. This is their prerogative, and all other organic life, parasitic vegetables, funguses and animals, depend for their subsistence on the plants that possess chlorophyll. The importance of chlorophyll must be my excuse for talking of it again (see p. 6).

Since all plants depend on the sun for their life and energy, there is no chance for seaweeds in a dark cave. They give the place up to animals. But these animals are nourished directly or indirectly by vegetables—mainly by the small floating algæ—and so they too draw their life from the sun.

Sunlight being as indispensable for a plant as meat and drink for a man, seaweeds grow where the light can penetrate. Only the mere surface of the ocean is a region of plant life. Depths of four miles and over have been explored by the dredge and the trawl, but no such thing as a non-parasitic and independent vegetable has ever been brought up from the abyss.[1] Plants, like the waves, are things of the surface. To come to more definite facts, there is no vegetable life, except possibly parasitic fungi and bacteria, beyond a depth of a hundred fathoms. Photographic plates exposed at a greater depth than this have been affected, but very sensitive bromo-gelatine plates exposed for ten minutes 222 fathoms down on a sunny day in March showed no trace of the action of light. Beyond a hundred fathoms there are no rays strong enough to be of any use to plants. Indeed, before that depth is reached, seaweeds cease to flourish luxuriantly. But though vegetable life is limited to shallow waters, and though animals are dependent on vegetables for subsistence, yet the dark abysses are peopled with animals. How that is possible I leave undiscussed for the present. First let me speak of the life in the shallow waters by the coast, and the floating life of the surface called the Plankton, small organisms which may swim in their diminutive way, yet are mainly the sport of currents and tides.

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[1] See Hickson's *Fauna of the Deep Sea*, p. 25.

Life in the Shore Waters

Everyone knows the seaweeds that cover the rocks, bright green often those that are quite near the edge, the rest red or brownish green. The last is the predominant colour of the three. But whether the colour is green, red, or brownish green, it is a marine form of chlorophyll, and corresponds to the green of land plants. The colour tells us that the stuff is there which breaks up the carbonic acid in the air or in the water into carbon and oxygen, and from the former of these two builds up the living organism, taking the radiant energy of the sun and making it the property of the plant. But below a depth of a hundred fathoms, as I have said, there is no sunlight, and there chlorophyll would be useless lumber.

Our largest seaweeds are like broad ribbons, six feet or more in length. Often we find them strewing the shore after a storm, and we are struck by their great size. But it is worth while considering why the largest seaweed is so small compared with a forest tree. It is true, I believe, that in some places, *e.g.* on the coasts of the Falkland Islands, they attain to a length of a good many yards, but compared with an oak tree or a sequoia they are but pigmies. To begin with, if big stiff-limbed trees grew in the sea, they would be liable to have their buds, shoots, and branches broken off by the waves. Moreover, they would have no soft soil to grow in. Sand and mud on the sea bottom shift with waves and currents. And so seaweeds pedestal themselves on rocks, but they send out no roots. And they labour under yet another disadvantage: the sunlight they get is dimmed, even for those that grow not far below the surface, by its passage through the water. And yet the luxuriance of seaweeds is wonderful. They form rich waving forests, in which all sorts of marine animals live. Planted on the rocks or on the seaweeds themselves, swinging with their waving ribbons or buried under their bases, are numberless tunicates (p. 26), worms, hydroids (p. 26), polyzoa (fig. 14, p. 36), sponges, to say nothing of the great variety of fish to be found there. But it is mainly the floating microscopic algæ (seaweeds, that is) that form the basis of the food supply of marine animals.

Richness and variety of marine fauna

There is nothing more astonishing than the richness and variety of the marine fauna. The whole vast ocean is a nursery of animal life, and the nurslings, in their variety, are worthy of the nursery. It can boast of whole groups of animals which in fresh water are entirely unrepresented or represented but meagrely. Fresh water can show no tunicates (there is no fresh-water sea-squirt—never mind the "bull"), no starfish, no fresh-water urchin, to match the sea urchin, no crinoid (the crinoid is a fixed starfish on a stalk), no octopus, no cuttle-fish. There is only one fresh-water hydroid, and that is very local; only one fresh-water jelly-fish; no fresh-water anemone, no coral animals. The polyzoa are rare in fresh water, though some are very beautiful. The fresh-water sponges are few and poor. But nothing can stale the infinite variety of the sea. Think of the fish! Besides the fish of commonplace build, such as the cod, the herring, the whiting, the dog-fish, the conger, there are the strangely distorted flat-fish, the sucker-fish, the angler, the flying-fish, the sea-horse, and many other forms. What have pond, lake, and river to set against all these? The salmon, the pride of the river, has, like the eel, a divided allegiance. To put it briefly and completely, as the ocean is to a lake in point of size, so is it in variety of fauna.

Dredging

If one goes out dredging, using only a small dredge, say two

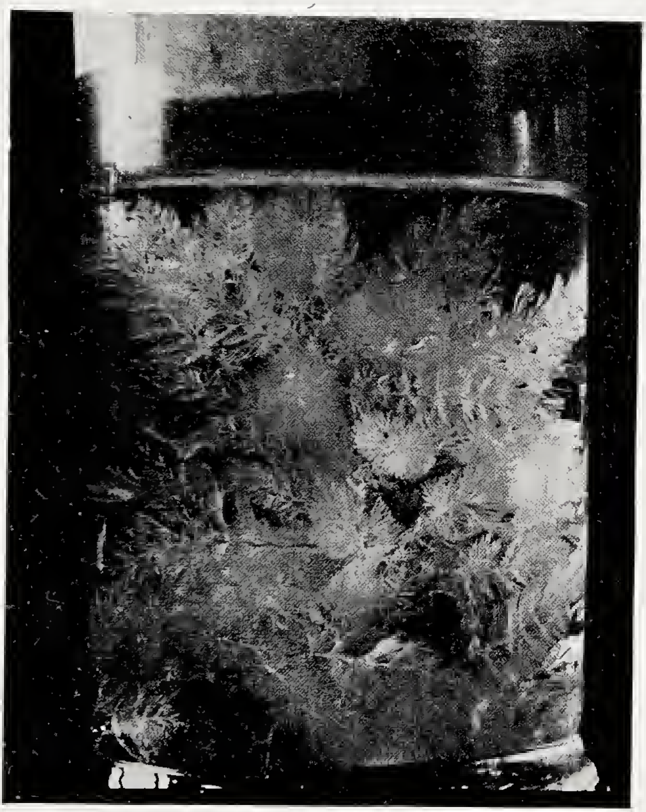

FIG. 14.—A Polyzoon (Bugula turbinata), a colony of animals (zooids). By means of cilia each zooid sweeps food into its mouth which does not, as in hydroids, lead into a *cul de sac.*

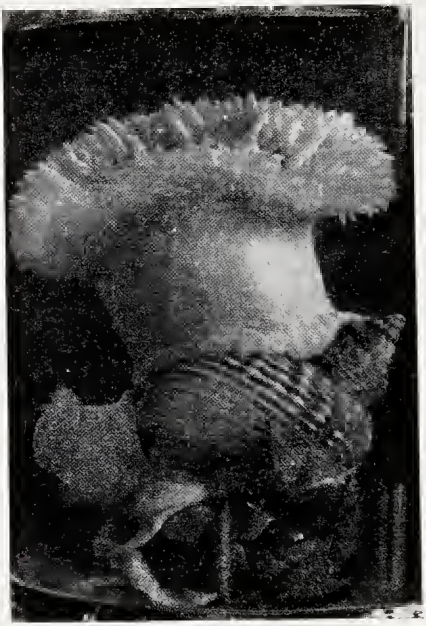

FIG. 15.—Hermit Crab and Sea Anemone (Sagartia parasitica), two messmates. An example of commensalism. Height of Anemone, 3 inches.

Facing p. 37

or three feet in breadth, it is wonderful what an enormous variety is often the product of one haul. With a rowing-boat some effectual dredging may be done, though the pulling is hard work. With a sailing-boat it is sometimes difficult to regulate the pace. It is important to go with the tide if there is any, else the dredge will jump and there will be but a poor catch. A small steamer is obviously best. But it is a poor thing to do nothing because that is not available. The sight of a good miscellaneous catch when the dredge is emptied on the deck, a catch ranging through the main classes of the invertebrate world, with a few sea-squirts to suggest the vertebrates, the hunt for small creatures that lurk among the seaweeds and the shells —this is to be counted among unadulterated pleasures, and certainly it is enough to convince one that there is no place like the sea for the variety of animal life, of invertebrate life at any rate. True, there are no insects, for they are air-breathers ; the crustaceans take their place. Allow that this deduction must be made, yet what a mine of wealth remains.

Partnerships

Some strange phenomena of animal life are seen to more advantage in the sea than elsewhere, or seen only there. Take that of commensalism or messmatism. In the sea we find frequent examples of it, but few or none in fresh water. There is a hermit crab which carries on its shell an anemone (fig. 15, p. 37). The anemone thrives on the shreds that are scattered by the clumsy feeding of the hermit. The hermit is defended by the anemone, who is armed with strings of little poisonous darts. Very often the shell has another tenant out of sight, a scavenger worm. What does the anemone do when the hermit moves house ? A difficult question to answer. For the hermit too, house-moving cannot be a comfortable business, his soft and appetising person having to be exposed, while he is transferring himself to a new shell, to the greedy eyes of any voracious fish or other enemy who may be lurking near.

Sometimes the hermit crab inhabits a sponge, the sponge picking up atoms of his food and the crab being protected by the presence of his messmate, who is nauseous to predatory fish and other animals. In this case there is *always* a third partner, a worm which acts as scavenger and keeps the hermit's house clean. This is very necessary, since the sponge-house is elastic and consequently he does not shift his quarters, as he is bound to do periodically when he lives in a shell. Hermit and sponge, it seems, start partnership in this way: the hermit takes up his quarters inside a little shell, and then the sponge happens to settle on the outside. The sponge grows all round the shell except where the hermit's head and legs look out. Many partnerships require further investigation. The caprella, a funny little crustacean, lives on Tubularia (fig. 11, p. 26), holding on by his hindmost appendages, and being no doubt protected by the hydroid. But what, if anything, he does in return is not clear. If it is an entirely one-sided affair, the caprella contributing nothing to the common good, it is a kind of parasitism.

Parasites

Parasites, unwelcome guests who live on their unwilling hosts, are common in the sea as on land. They are degraded creatures, having lost many of the organs which alone make an independent life possible. Parasitic worms, for instance, may be found in fish or in sea-urchins. Many small crustaceans attach themselves to the skin or gills of fish, *e.g.* Caligus (fig. 17, p. 41). Sometimes a crustacean is a parasite on a crustacean. On the under side of a crab's tail (more correctly abdomen) is sometimes found what looks like a pea. This is the celebrated Sacculina, noted even among parasites for its degraded condition. Professor Hickson describes it as a "skinful of eggs."[1] It sends "root-like processes" into its host, and through them gets all its nutriment. Yet when young it is what is called a nauplius, and with as much power of swimming as the young barnacle (see p. 32). Now it has sunk low indeed. As far as I know, fresh water has no such parasite as this to show among its crustaceans.

When we put beside this wealth of marine forms of life the meagre display that the fresh-water ponds, lakes, and streams present to us, we must conclude that he who aspires to have a general knowledge of Natural History cannot afford to omit marine zoology. If this is not to leave out the part of Hamlet, it is to leave out a great deal. But as yet I have said

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[1] See *The Story of Life in the Seas*, p. 168.

Mammals of the sea

nothing of the mammals whose home is the sea—the whales, the dolphins, the porpoises, the seals, the sea-lions, and the walruses. When we see the vigour and endurance of the porpoise, how he keeps up with a ship that is going, say, nine knots an hour (I give a moderate estimate so as to be well within the mark), and seems to take a pleasure in swimming round it, as if to show his superiority, we cannot help concluding that for its physical powers we must put it above all the cold-blooded animals of the sea. All the marine warm-blooded animals, the whales, the porpoises, the seals and their allies, are mammals, and belong to a higher stratum of life than any other inhabitants of the ocean. Undoubtedly we must rank them first, the whales for their portentous bulk and enormous strength, the porpoises and dolphins for their speed long maintained, the seals for their courage and endurance, for an old male will go for weeks without food when he is defending his harem against his rivals. But we cannot call the seals entirely marine, for besides being air-breathers, they bring forth their young upon the land and spend much of their time there. The porpoises and whales also come to the surface to breathe, so they do not belong wholly to the sea. They gain enormously through getting ample supplies of oxygen from the air. Why is it, then, that these mammals, so pre-eminent in vigour, are so few in number? It has, I believe, partly to do with their method of breathing, by which they lose as well as gain. In a race, pursuer or pursued clearly has an advantage if he is in his own element and has not to go to the surface to breathe. If these marine mammals could only get their oxygen from the water, what could they not catch and kill! By breathing air which is many times as rich in oxygen as water, they gain greatly in vigour. Their rate of combustion is much greater, and consequently their output of energy. But they have to pay for their gain. Just as steamers, though enormously faster than sailing boats, are hampered by the necessity of perpetually coaling, so the seal, the porpoise, and the whale are hampered by the fact that the water in which they swim has no oxygen that they can use. Moreover, the seals cannot go very far from land, since they sleep and bring forth their young there.

The great seal rookeries, as they are called, are easily accessible, and those seals that have any commercial value are slaughtered in great numbers. In this way they are worse off than the whales. The latter would have been exterminated long ago were they in the habit of venturing on the land. But they have other difficulties, about which it is wonderful how little we learn from books on whales. The young whale has to be suckled, a very difficult matter without a departure from the ordinary habits of the adults. A bull Sperm whale will remain under water for over an hour. A half-hour's dive is not uncommon. The Humpback whale, Captain Scammon tells us,[1] goes to "inland waters connected with the ocean" to bring forth her young, and there, in shallow lochs, the mothering of her infants is a comparatively easy matter. Do all whales choose for their nurseries such shallow sequestered waters? Porpoises, I think, do not leave the open sea.

The Floating Life of the Surface Waters

We will now inspect the Plankton, all that minute life which, though some of its representatives may swim actively, yet mainly floats and drifts with the tides and currents. What an amazing amount of life there is in the surface waters! Buy or make a Tow-netting tow-net. To make one, take a piece of fine muslin or bolting silk[2] and make it into a long bag, fastened round a hoop at its open end and leading into a glass jam-pot at the other. Tow this behind your boat while you row gently for a quarter of an hour. Generally at the end of the time you will find such a mass of microscopic life in the pot, with a few big monsters among the small fry, that unless you add more water, asphyxiation will soon bring about a huge death-rate. When a tow-netting is described as poor, it generally means that not many species are represented in it, though there are individuals in shoals. Most abundant in tow-nettings, even monotonously and provokingly abundant, are Copepods the Copepods (figs. 16 and 17, pp. 40 and 41), the food of the herring, for the herring does not, as fishermen will assert, live on

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[1] *The Marine Mammals of the North-Western Coast of North America.*

[2] This can be obtained from the Manchester Wire Works (Messrs Staniar).

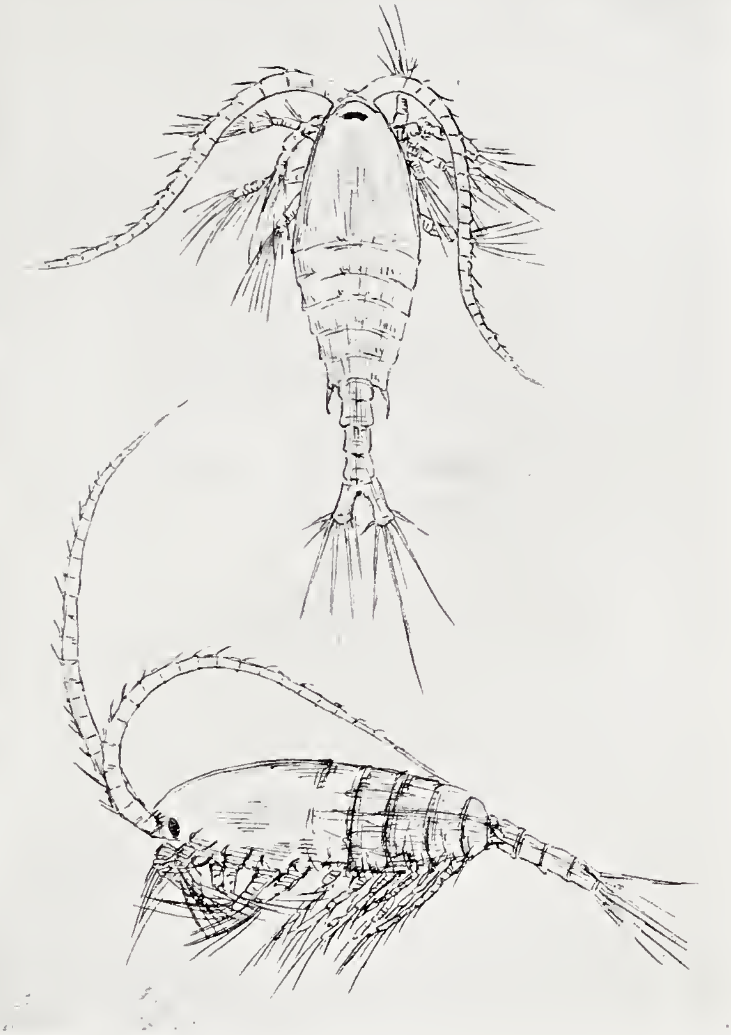

FIG. 16.—Typical Copepods (×60 diameters). They have one eye; hence the name Cyclops for the fresh-water form.

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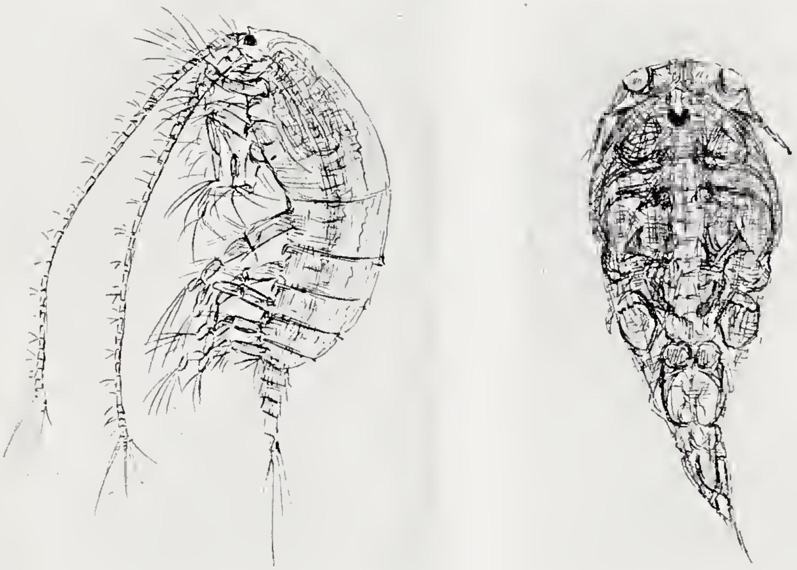

A B

FIG. 17—A, a free-swimming Copepod; B, Caligus, often found clinging as a parasite to the skin of codfish by means of its round suckers, often also living an independent life. Both ×60 diameters.

Facing p. 41

water, but on these minute crustaceans. Generally in them may be seen globules of oil, the purpose of the globules probably being to give them buoyancy. For the fish his swim-bladder, for the copepod his fat-globules. If we reflect that the copepod, like the Flying Dutchman, must keep for ever in motion, we can understand that some form of float to make swimming comparatively easy for him is much wanted. Certainly he must always be moving if he is a copepod of mid-ocean. Impossible for him to take a few hours' rest on the bottom, then rise to the surface. And there is hardly a doubt that those which are found near the shore never go to the bottom. They are always swimming, swimming, gently or with great jerks. For their slow, easy gait they use their swimming feet; for their powerful, jerky strokes, their antennæ, which are long and strong.

In spring there are often countless swarms of Diatoms and Infusorians; among the latter, Ceratium tripos (fig. 1, p. 5), perhaps, the commonest. Small medusæ are often scattered thickly in the water. Often Oikopleura, an ascidian which keeps its tail throughout life, is abundant. Then there are the larval forms of crabs, of lobsters, of barnacles, of worms, of the sea-urchin, of starfish, of many sorts of mollusc, all of them except the larvæ of the crustaceans swimming by means of cilia, very minute threads of protoplasm which they move continually. Besides these there are many still more minute forms of life which escape detection unless they are examined under the microscope with an objective of fairly high power. If such minutiæ were not there, on what would copepods and such giants of the microscopic world subsist?

Globigerina

In the surface waters of the ocean are myriads of small animals belonging to the same class as amœba. Each is a tiny blob of protoplasm which sends out threads or tongues and swallows its food by making a mouth where it is wanted. But they differ markedly from amœba, for they have shells. Globigerina, one of the commonest, forms its shell of carbonate of lime.[1] It has often a number of chambers, but they communicate with one another. Its surface bristles with a forest of slender spines, said by Sir Wyville Thompson to be pliant, and which, pointing as they do in all directions and being often five times as long as the diameter of the shell, cross each other and form a veritable jungle. The shell has one big aperture or many minute ones through which Globigerina protrudes thin threads of protoplasm, threads of his undifferentiated self. Such a shell would seem to make swallowing amœba-fashion difficult, but apparently the food is so minute that when it has been absorbed by a protruded thread of protoplasm there is no difficulty in drawing the thread in. The Radiolarians have a skeleton of flint, and this is the main difference between them and Globigerina. In either case the skeleton is of a heavy material, and the question is why they float so buoyantly.

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[1] Fig. 18, p. 42.

Radiolarians

In the first place, their skeletons with their multitudinous projections have a very great surface in proportion to their weight, and in the case of the Radiolarians the protoplasm contains vacuoles in which there is a watery fluid, and, besides this, one large vacuole containing oil. Hence they obtain their buoyancy partly in the same way as the copepods.

The food of the coral polypes

When people first hear of this teeming microscopic life of the seas, they are nearly always astonished. It is the coming of a new world into their ken. And yet but for these swimming minutiæ, some familiar facts would be inexplicable. Everyone knows of the existence of coral islands, and nearly everyone knows that coral is built by an animal with the lime which it secretes, as a snail secretes its shell. I think they know this, though they commonly speak of the coral animal as an insect, a comprehensive term in its popular use meaning any small creature, whereas the builder of the coral reef is properly called a polype and is a near relative of the sea-anemone. It has a ring of tentacles surrounding its mouth, and for defence has its nematocysts, or strings of little poisonous arrows. The polypes live in colonies and build for themselves skeletons of lime (figs. 19 and 20, pp. 43 and 44). These great colonies composed of many minute individuals, living and thriving in the ocean, especially in the Indian and Pacific Oceans, must have food to live upon. They thrive best where there is a moderate current drifting towards the

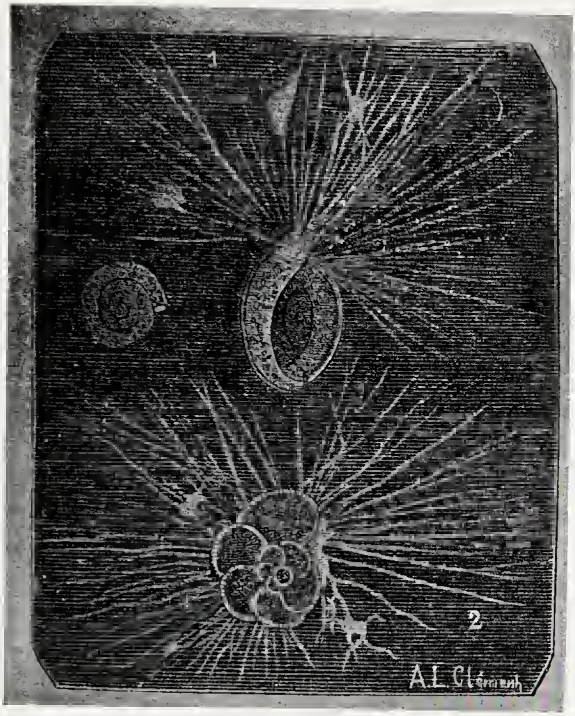

Fig. 18a (after Filhol).—Foraminifera, to which order Globigerina belongs. (1) Miliola tenera; (2) Cornuspira planorbis. In these the shell has only one aperture, in other species there are many minute ones. The sarcode (protoplasm) runs along the flexible calcareous spines, ingests food (see among spines), and withdraws into shell. The different chambers (2) open into one another.

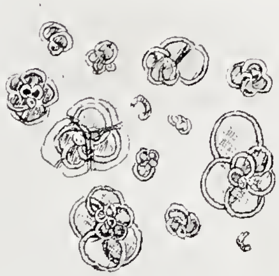

Fig. 18b.—Shells from Globigerina ooze (× 100 diameters). Their spicules have been broken off.

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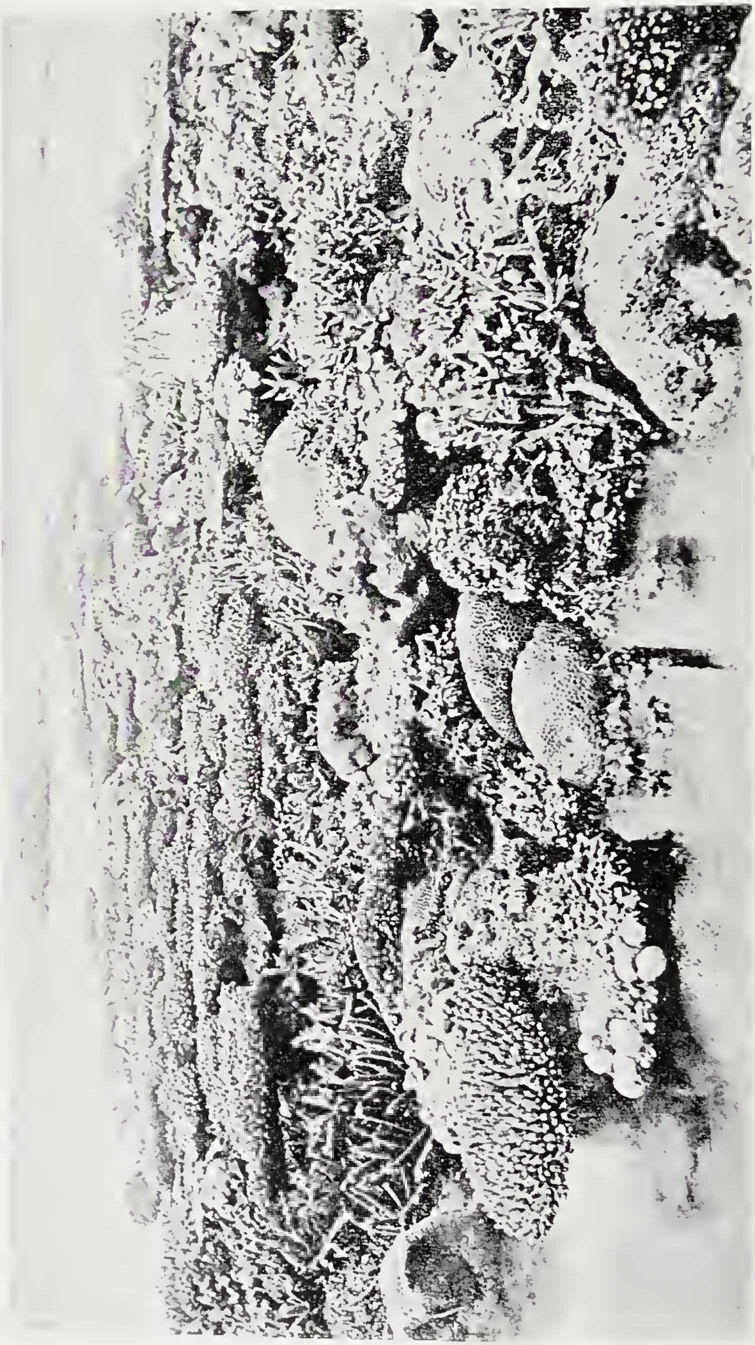

FIG. 19.—On the Great Barrier Reef of Australia. From a photograph by Mr Saville Kent.

Facing p. 43

reef. On the lee side they grow less vigorously. And their food is, no doubt, floating microscopic creatures, vegetable and animal, representatives of the Plankton with which every current is laden. They catch their food with their tentacles, or, I am told on good authority, simply allow it to be swept into their mouths.

Consider the work of these coral polypes, how they alter the face of the globe. How they start some forty fathoms below the surface, for the reef building corals—the builders of the countless reefs and atolls that dot the surface of the Pacific and the Indian Oceans—cannot live and thrive at greater depths : how they make a settlement wherever there is a suitable foundation, and build upward till they reach the surface. If the foundation subsides, for *terra firma* is given to subsiding and to rising, they raise their island till they again reach the surface.

Theories of coral islands

The subsidence may lead to the disappearance of the island which the reef encircled, and so the reef may become an atoll or mere hoop. If well supplied with food, the polypes will build their reef outward, so that it grows like a fairy ring. Probably it does not make very much advance in this way. But, granting this, it is marvellous that these tiny organisms should be able to build a rampart that not only remains undestroyed by the waves and currents, but actually makes headway against them—a living rampart that takes the offensive. All this these polypes achieve, causing geologists and zoologists to hold rival theories about them, one party maintaining the theory of subsidence and the vanishing of the island in the middle of the ring—hence the atoll or mere hoop—the other pinning their faith to the fairy ring theory and the gradual death and dissolution of the coral in the middle—hence the atoll or mere hoop. "How without subsidence," the subsidence party ask, "account for so many mountain tops rising from enormous depths nearly to the surface, just to the right distance from the surface for the coral polypes to build upon?" "The waves will sweep away islands—loose stuff thrown up by volcanoes," reply the fairy ring party, "and the débris of dead animals will fall and accumulate on any mountain top that comes short by a good many fathoms of the requisite elevation, till it is built up to the level at which the polypes can live and thrive." Let us leave these rival theories. One does not exclude the other. In one place subsidence may have been going on, in another the reef may have been formed without it. Those who are lucky enough to be able to inspect coral reefs for themselves, seem most of them to come to the conclusion that subsidence has not been general. But as to one thing there can be no doubt, that these marvellous builders whose edifices are sprinkled over the Pacific on either side of the equator within the limits of the genial warmth that they need—these marvellous builders are nourished by the small floating population of the surface, minute plants and animals of which the currents bring them a regular supply. Microscopic floating algæ abound in these regions. Big seaweeds are poorly represented. There are stony seaweeds called Nullipores, which themselves contribute a kind of coral to the reef. But in the lagoon inside and on the slope outside, generally a steep slope, seaweed seems noticeable by its absence. On the reef itself there is but little variety of seaweed. One hears of Nullipores and nothing else. It must be remembered that a marine plant has no roots. Probably an ordinary leafy seaweed, when left bare by the tide, would be scorched to death by the tropical sun.

Plant life in tropical seas

Well, it is the Plankton, the tide of minute floating things, that feeds the builders of the reef. But we shall get a very incomplete idea of what the Plankton can do unless we study the life of the reef. To begin with, there is a wonderful variety of the corals themselves, showing on some reefs the most gorgeous colours—purples, blues, greens, yellows and reds. Mr Saville Kent's book on the *Great Barrier Reef of Australia* has splendid photographs of the reef, and also plates showing the colours of corals. The Madrepores are the great builders that breast the waves and the currents. But inside the lagoon, near to some place where the tide has made a gap in the reef, and consequently a stream teeming with microscopic life rushes in—it is there, apparently, that you find the more delicate corals and the greatest variety of species.

Colours of the corals

There is no end to the forms of life that are associated with the corals. Among the fixed forms there are sponges and Nulli-

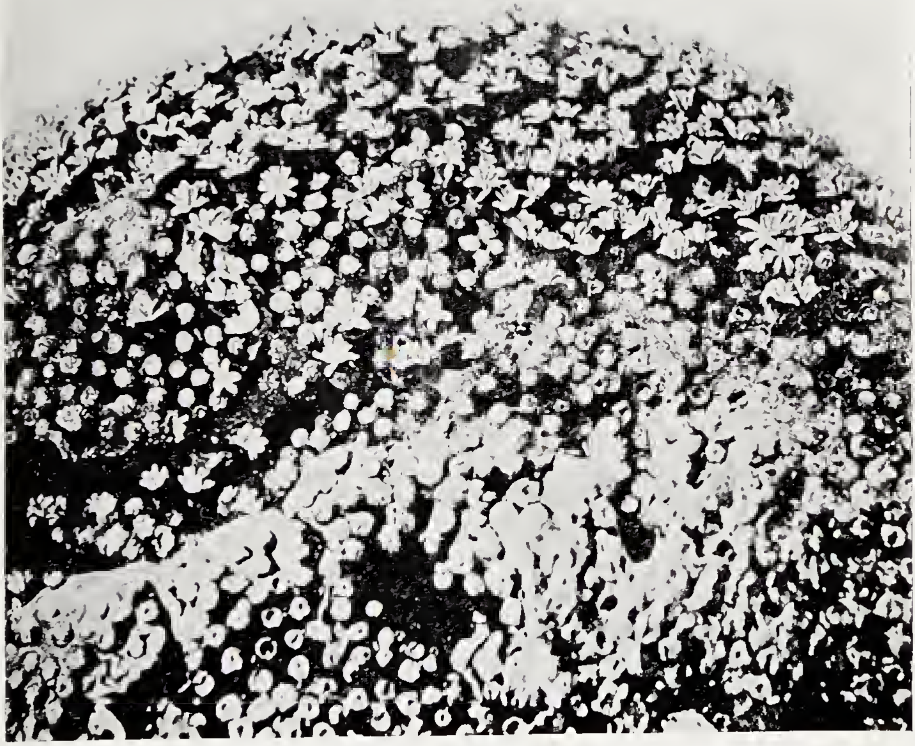

FIG. 20 (after Saville Kent).—Organ-pipe Coral, photographed while the polypes were expanded under water.

pores. Professor Hickson, who has visited and made a stay upon coral reefs, and studied their life, dilates upon the hosts of the starfishes, the sea-urchins, the brittlestars, the sea-slugs, and the molluscs that crawl about among the branches, while "crabs, lobsters, and shrimps may be seen swimming or crawling in search of their prey, and the marvellously striped and spotted coral fishes dart hither and thither in the thicket."[1]

Colours of the fish among reef corals

The colours of the fish are beyond all description. The plates in Mr Saville Kent's *Barrier Reef of Australia* show us blue fish with red-orange bands, others with scarlet bands. "Too brilliant to exist" is one's first thought. But the most brilliant fish are found where the corals are most highly coloured, and, no doubt, the gorgeous hues of the fish are protective. In very brilliant society, to be dull is to be a marked man. A brilliant star may attract little notice.

For those, the great majority unfortunately, who can only know what coral reefs are from the description of others, I recommend, besides the books I have mentioned, Professor Hickson's *Naturalist in Celebes*, and Darwin's *Coral Reefs*. Such books will at any rate teach us not to look upon corals, when we see them in collections, as mere curious stones, but to associate them with one of the most wonderful forms of life.

So much on the subject of coral reefs. I have given this brief account of them in order to show how rich must be the Plankton that supplies the polypes that build them with nourishment.

Life in the Depths

We will now leave the surface and plunge into the abyss. Sixty years ago, men of science were almost unanimous in believing that the depths of the sea were altogether devoid of life. There were what seemed good grounds for this belief. No vegetables could live in that Cimmerian darkness, hence there could be no animals. This might well be considered proof so conclusive that there could be no need to produce further arguments. But if further proof was wanted, it was easy to say that without free oxygen there could be no animal life, and that the water of the

[1] *The Story of Life in the Seas*, p. 61.

abyss, miles away from the breezes of heaven, could not possibly be oxidised. Still, nature often asserts her independence of the theories of men of science. The facts gradually came out. Worms came up attached to sounding lines and reopened the question. In 1847, Sir James Ross, the great Antarctic explorer, gave good grounds for his conviction that a deep-sea fauna existed.

When the possibility of laying electric cables across the Atlantic was being discussed, the question of the nature of the ocean bottom became an important one. Not only the few who care for science, but the many who care for things commercial, began to be interested. The commercial spirit and the scientific spirit for once worked together, and the result was the sending out of the Challenger Expedition in 1873, which, grandly designed and grandly carried out, has been one of the great achievements of our nation. The *Challenger* was a vessel belonging to the Navy, a corvette of over 2000 tons. She carried the best scientific apparatus that could be devised. There were dredges and trawls, there were bottles which opened only when they touched the bottom, and which brought up water from the lowest depths to be analysed, and other bottles which could be made to open at any depth. There were thermometers to take the temperature of the abyss. There were, of course, leads and tackle for sounding. More important than all, the men of science to whom the direction of the expedition was entrusted were highly competent and enterprising.

The Challenger Expedition

The bulky volumes of the Challenger report, forty of them and over, describe and figure the spoils that were gathered from the deep below the deep. Much still remains to be found out, but the ocean bottom is no longer a terra incognita. We have a general knowledge of its very remarkable fauna.

Oxygen and food in the abyss

How, then, is life possible there? When the fact of its existence was made known by the dredge, when fish, ascidians, crustaceans, starfish, molluscs emerged from miles below, then the new facts dredged up set keen minds hard at work thinking. As to oxygen, could it be that there was a descending current that supplied the underworld with oxidised water from the surface? Could it be that the carcases of animals that died in surface waters slowly descended and fed those that dwelt far below? There is now no doubt that these things are so. As to food, we have this as our main argument, and it is enough: animals there are that live in the depths where there are no plants. They cannot live upon one another unless it be possible for the inhabitants of a small island (this is said to take place somewhere off the west coast of Scotland) to gain a precarious livelihood by taking in each other's washing. There must be, as a basis, some supply from outside. There must be some animals who depend upon importations, and who do not prey upon the other animals of the same association. And there is no doubt that it is the carcases that descend from the upper world of waters that feed the lower classes. What other basis of supply is imaginable? Moreover, we find what are called oozes forming a layer at the bottom. Down to a depth of 2800 fathoms we find a globigerine ooze, made up mainly of the very minute animals described above (fig. 18, A and B, p. 42). They sink to the bottom, and in the descent lose their spicules. There are species of *Globigerina* which live below, but the ooze is mainly formed of the shells of those that sink from the surface waters. And when the shell descends, apparently it brings with it some protoplasm still capable of affording nourishment. Were it not so, how could life in the abyss be maintained? At still greater depths there is a radiolarian ooze (see p. 42), the flinty shells of the radiolarians remaining undissolved during the descent, whereas the lime of the globigerinas is more soluble. In the Antarctic Ocean we find a diatom ooze. The diatoms (see p. 5) are extremely minute vegetables encased in a flinty envelope which is as near to being imperishable as any substance can be.

There can hardly be a doubt that the radiolarians, globigerinas, and so forth that sink to the bottom form the basis of a food supply in what would otherwise be a world of starvation. The more powerful animals, of course, prey upon the weaker, and do not condescend to touch the stuff that descends from above.

Now as to the downward current of oxygen-bearing water. We have evidence of various kinds to prove that it is a reality. The very fact that animals exist below proves that the water must be oxidised. The curiously devised bottle let down from the *Challenger* that brought up water from the abyss, put the fact of the existence of free oxygen there beyond all doubt. By free oxygen is meant the oxygen dissolved in the water, not that which combined with hydrogen constitutes water. When a pond is completely covered with ice, the fish in it die for want of oxygen. Yet there is plenty of that gas present combined with hydrogen. But it is unavailable.

A northward movement of water

The temperature of the abysmal water supplies further evidence of a downward current. In some parts of the Atlantic it is nearly six degrees below the freezing-point of fresh water (32° F.). If you go down into a deep mine the heat is considerable, it increases as you descend further. If the bottom waters of the Atlantic were not somehow chilled by the continual down-flux of cold water from the surface, their temperature would be higher than it is. Moreover, in the equatorial regions the surface waters—there is reason to believe—evaporate more rapidly than they are replenished by rain and rivers. In the Antarctic Ocean, on the other hand, rain and snow contribute more than evaporation removes. We may fairly infer this from the fact that the surface water of the Atlantic north of the equator is heavier and denser—its specific gravity is greater—than the surface water to the south of the line.[1] An equal amount of water, say a cubic foot, is taken from either region and weighed—the temperature must, of course, be the same in both cases—and the northern water proves to be the denser. The lesser specific gravity in the south is due to lesser salinity, and the lesser salinity is traceable to the excessive rainfall—to the excess of precipitation over evaporation. The water of the southern ocean finds its way northward where there is a deficit. It is also a very significant fact that all over the Atlantic the surface water is heavier and denser than the mass below. At about 400 fathoms the minimum density is reached. After that there is a slight, but only very slight, increase. Right down to the bottom of the abyss the specific gravity remains low. And where does the water with low specific gravity come from? No doubt it is the

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[1] See *The Realm of Nature*, by Dr H. R. Mill, p. 165, and Plate No. 8.

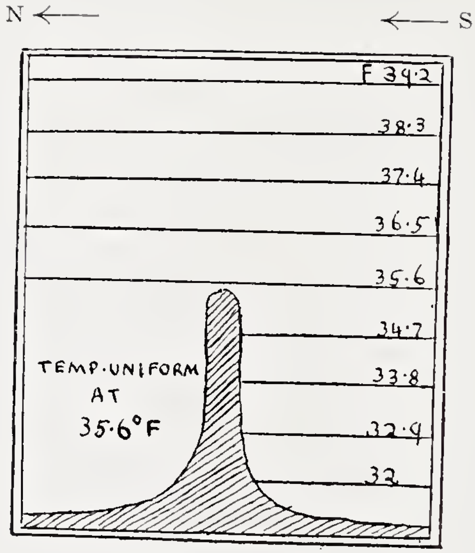

FIG. 21 (after Wyville-Thomson).—Diagram to explain the different temperatures in the S.W. and N.W. basins of the Atlantic. The arrows represent a current from S. to N.

Facing p. 49

surface water of the Antarctic region reappearing. But if it is not dense and heavy, why does it sink to the bottom? It must be remembered that a certain amount is taken by the man of science and weighed against an equal amount of more northern surface water *of the same temperature*. Under these circumstances its inferior density is due to lack of salinity (salt water is more buoyant to the swimmer than fresh because it is more dense). But when the surface water is chilled by cold breezes playing over it, its specific gravity goes up, it gains in weight and density, and sinks slowly down till the floor of the ocean prevents it from sinking further. Sea water, unlike fresh water, becomes heavier and denser until it freezes. The freezing-point at the surface is at about 28° F., varying with the salinity.[1] It is lowered by pressure, and this accounts for the fact that, in part of the Atlantic, water at a little over 26° is found at the bottom. Just look now at a map of the world, or better, at a globe if there is one handy, and see the extent of the Antarctic Ocean, that enormous reservoir. The Atlantic is a mere arm of it. Northward into this arm must be ever moving a cold current from the great reservoir, northward and also downward. Of this the thermometers let down by *Challenger* scientists brought up still more convincing evidence. The Atlantic is a great trough with a ridge running from north to south. Opposite British Guiana there is a barrier, a less defined ridge which, meeting the longitudinal ridge, divides off a south-western basin. In this basin the temperature at the greatest depths is just over 26° F., while at the top of the ridge it is only a little below 36°. In the north-western basin, though it has a depth of nearly 4000 fathoms, the temperature down to the very bottom is the same as it is in the southern basin at the level of the top of the ridge (fig. 21, p. 49).[2] What is the most natural way to explain this? The lowest and coldest layers of the current coming from the south are checked by the transverse barrier, while the rather less cold layers at a higher level pass unchecked and fill all the lower part of the northern basin. This argument and others for a northward-downward movement of water are very clearly put in Sir Wyville Thomson's *Voyage of the Challenger*.[1]

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[1] Dr H. R. Mill has very kindly given me some information on these points. See his *Realm of Nature*, p. 167, where the matter is explained.

[2] The lowest bottom temperature is, as I have said above, nearly 6 degrees below 32° F. In the figure Sir Wyville Thomson puts it at 32°.

Summary of arguments for a northward movement of water

We can now sum up the arguments on which the theory of a current creeping slowly northward from the Antarctic Ocean is based: (1) There is an excess of evaporation from the equatorial regions which must be made good from somewhere. (2) The Arctic Ocean is small and the Antarctic is immense. This immense ocean almost certainly has an excess of rain and snow, and it must give its superfluity to its northward stretching arms. (3) The low temperature of the Atlantic at the bottom of the south-western basin can only be accounted for by the assumption of a current from the Antarctic. (4) There is the barrier argument (see p. 49). The bottom temperature of the north-western basin of the Atlantic and that of the layers of water next above the lowest are difficult to explain unless we assume a current from the Antarctic Ocean. (5) The water of the abyss is rich in oxygen. This seems to clinch matters. This oxidised water must come from the surface. It is very cold, and must come from regions of great cold.

The barrier opposite British Guiana, with its different bottom temperatures on the north and on the south, seems to picture to us the slow but ceaseless movement of the waters northward.

Light in the Depths

Fish with power of sight

Something more now of the life in the depths. Here is a fact that seems to make fiction tame and commonplace: many of the fish that are dragged up from the gloom of Erebus, from depths miles below the regions to which the last gleam of sunlight penetrates, have eyes, not poor atrophied organs, but eyes possessed of the power of vision, and not only fish, but some crustaceans, worms, and cephalopod molluscs. Knowing that blindness was the invariable characteristic of the fish of the great Kentucky caves; that the Proteus, the amphibian of the

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[1] Vol. ii. pp. 315-328.

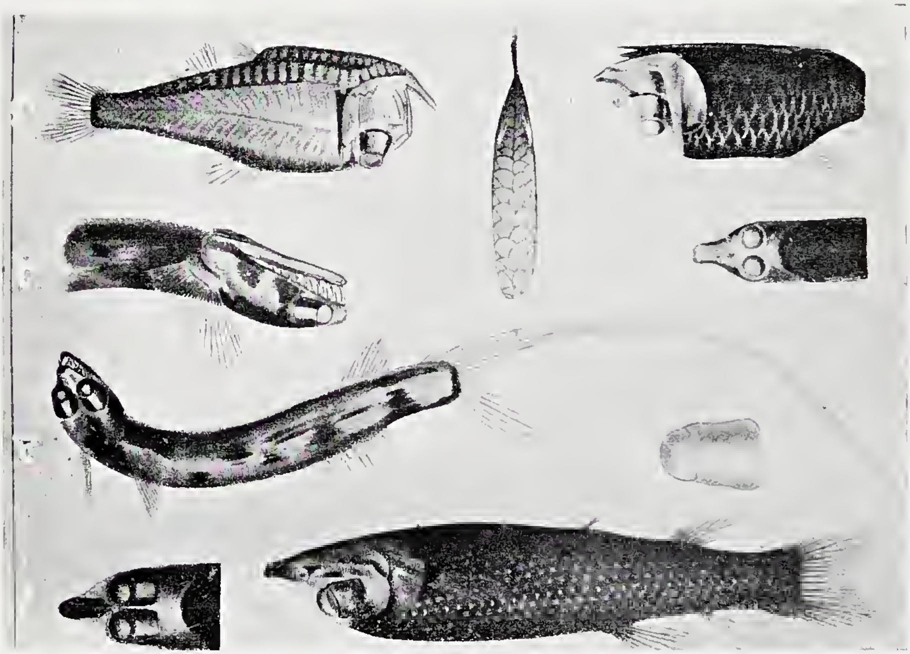

FIG. 22 (after Chun).—Fish with "telescope eyes," from deep but not bottom waters. (1), (2), and (4 on left), from Gulf of Guinea; (3), from Somali coast; (1), from 660 fathoms, (2) 1400, (3) 550, (4) 2200. All about half actual length.

caves of Carniola, is absolutely blind; knowing Nature's rule that when an organ becomes useless it tends to degenerate and leave but a vestige of itself; what zoologist would have ventured to prophesy that any inhabitant of the sunless abyss would turn out to be endowed with the power of sight? And yet the fact is that many of them have this power. Some deep-sea fish, and even one species of cephalopod, have what Professor Chun has described as "telescope eyes," some horizontal, some directed upward. They do remind one of the barrel of a telescope (fig. 22, p. 51). As to the explanation of this remarkable form of eye, I venture a suggestion. Near-sightedness is usually due to the bulb of the eye being unduly long from back to front. Now, many of the deep-sea fish carry their own lanterns in the shape of phosphorus patches, often found near to the eyes. In any case the light must be dim, except in the near neighbourhood of a lantern of some sort. To a deep-sea fish, then, it may be of advantage to be near-sighted, to be able to focus his eyes on objects at very close range. No doubt there is in particular places, or at times when lamp-bearing forms congregate, a general, though not very effective, lighting. Most classes of deep-sea animals seem to count among their number some luminous species. Probably some of the Radiolarians show a phosphorescent light. Hydroids, starfish, brittlestars, worms, crayfish, shrimps, fish, in short nearly all classes contribute to the illumination. M. Filhol, in his excellent book, *La vie au fond des mers*, has coloured plates which perhaps give some idea of what the amount of light may be. It may in some places, possibly, be lighted as well as the streets of a small town at night that has only old-fashioned gas-lamps. In surface waters do not the little noctilucas give a brilliant light, especially when the waves curl over? Sir Wyville Thomson says that he was once able to read at night on the deck of the *Challenger* by the aid of the phosphorescent illumination: "The unbroken part of the surface appeared pitch black, but wherever there was the least ripple the whole line broke into a brilliant crest of clear, white light. Near the ship the black interspaces predominated, but as the distance increased the glittering ridges

Phosphorescence

looked closer, until towards the horizon, as far as the eye could reach, they seemed to run together and to melt into one continuous sea of light. The wake of the ship was an avenue of intense brightness. It was easy to read the smallest print sitting at the after-port in my cabin; and the bows shed on either side rapidly widening wedges of radiance, so vivid as to throw the sails and rigging into distinct lights and shadows."[1] This display of fireworks by minute Infusorians is a truly marvellous thing. But it was quite exceptional in its brilliance. We cannot imagine that any region of the sea, in the depths or near the surface, normally, or even frequently, enjoys an illumination of so many thousand candle-power. Moreover, we must remember that a light, however brilliant, will not penetrate far through water. The abyss can be but dimly lighted. To see clearly, a fish must be near a torch, whether it be his own or that of some other torch-bearer.

There must be enough light to see by in the depths or the inhabitants would not have the power of sight. When an artesian well throws up with the first jet of water fish that have eyes that can see—a not uncommon phenomenon this in the Sahara—we may feel sure that the water below communicates somewhere with a lake or stream that is open to the sunlight. In the same way in the abyss of the Atlantic, eyes that have the power of vision are good evidence that there is light there though it is not the light of the sun. But what is the advantage to a fish of being his own linkboy? Why bear all these brilliant patches? Might they not even be injurious, attracting enemies or warning off possible victims? It may be so, but it is easy to see that sight may be useful. Most of the crustaceans are blind, and a lamp, therefore, would not startle them, while it would certainly help a predacious fish to find his blind quarry. So we can look upon the phosphorescent patches on fish as torches. The German Deep-Sea Expedition has thrown light on this subject. Professor Chun examined the fish in the darkroom directly they were brought up by the dredge and so discovered much that might otherwise have remained unnoticed.

Use of phosphorescent patches

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[1] *Voyage of the Challenger*, vol. ii. p. 85.

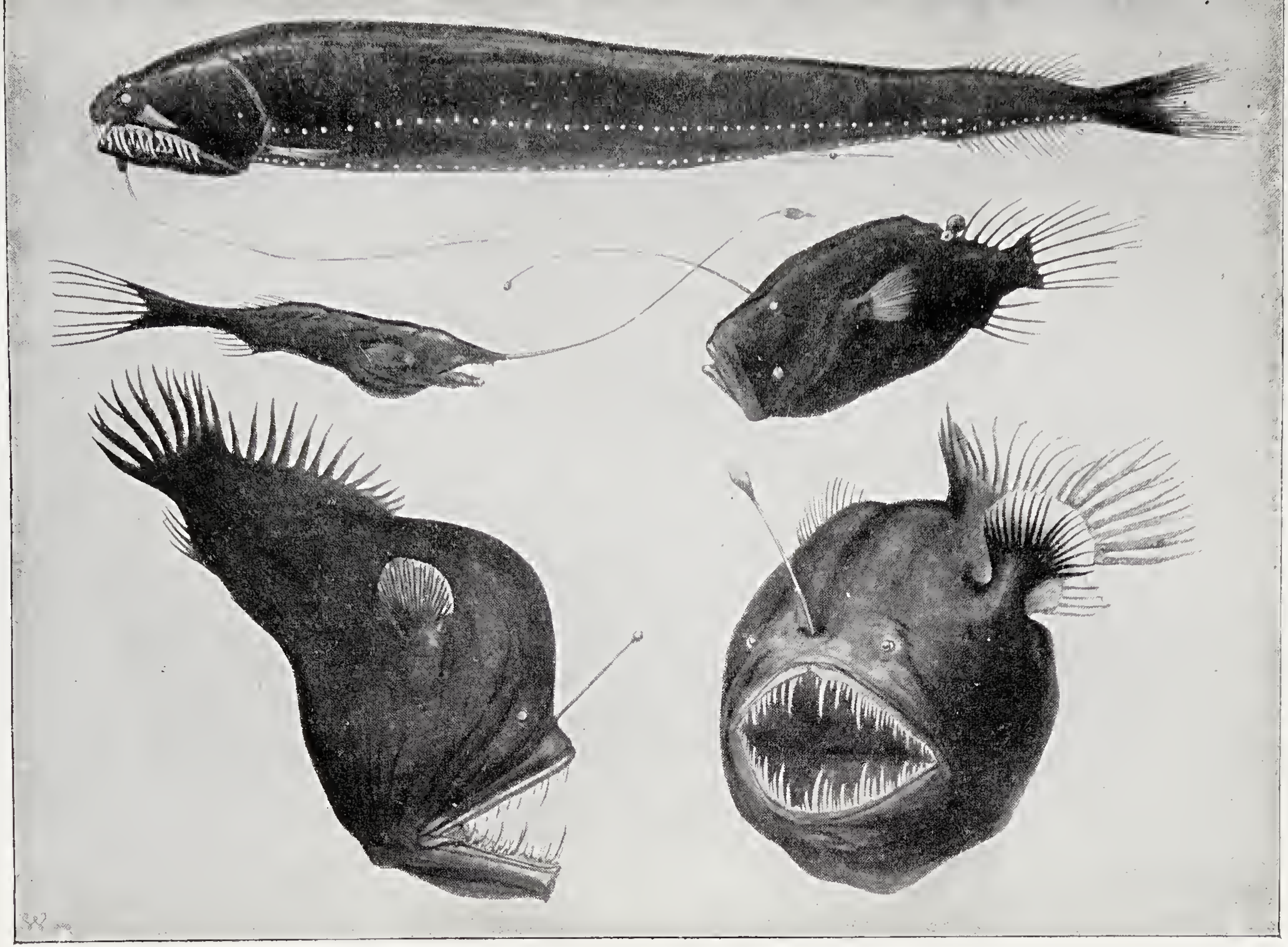

FIG. 23 (after Chun). —Fish from great depths, but not from the bottom of the ocean. (b) and (e) natural size; (a), (c), and (d) slightly reduced. Phosphorescent patches

a

b c

d e

behind eye in (a) believed to be under control of nerves; long barbels for tactile purposes. The long appendages over the snouts of the four "Anglers" are believed to be phosphorescent.

Facing p. 52

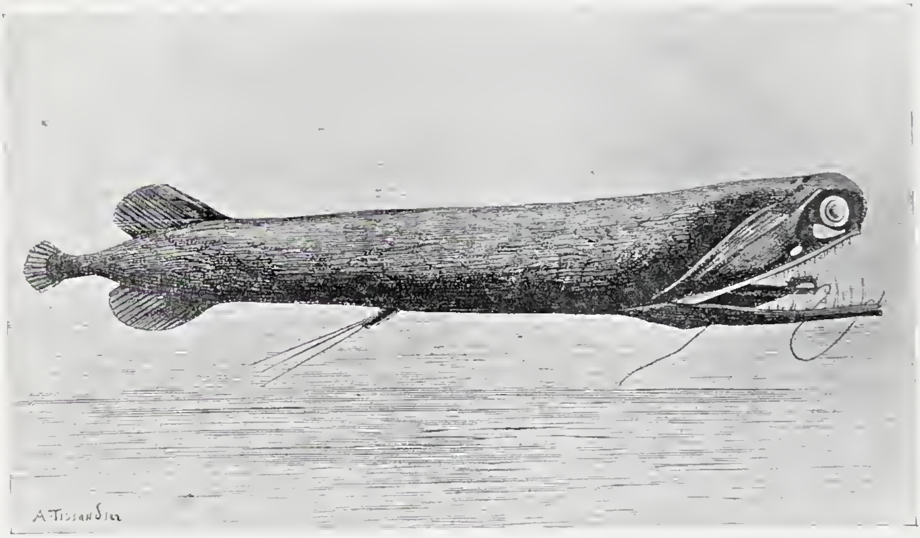

FIG. 24 (after Filhol).—Malacostens vigor, dredged from 800 fathoms off Morocco coast. Actual length, $5\frac{1}{2}$ inches; colour, black. Brilliant patches of phosphorescence below the eyes.

Facing p. 53

He found that in some cases these lamps are under the command of voluntary muscles, so that the fish can at pleasure switch on the light or switch it off. Echiostoma (fig. 23, p. 52) has this power over the brilliant lights behind its eyes. A good many deep-sea fish have rods, possibly continuations of the back fin, running out from the ends of their snouts and ending in a kind of bulb which is believed to be a phosphorescent organ. If this too were under command, the fish could use it like a bull's-eye lantern.

No doubt, these lights do serve as lanterns, whether thus under command or not. But I wish to suggest a further use for them, and especially for the patterns marked out in phosphorescent light that sometimes extend from end to end of the fish. They may serve as recognition marks. There must be some means by which individuals belonging to the same species may recognise one another. A bird knows its kinsman, there is good reason to believe, by its plumage or its voice. In the dim light of the ocean deeps it must be difficult to recognise a friend unless he carries a light peculiar to his kind. It is true that fishes have the sense of smell well developed, if we judge by the size of the olfactory lobes of their brains; but scent is not likely to carry so far as the brilliant phosphorescence of some deep-sea fishes. And certainly these phosphorescent patches are in some cases definite and characteristic enough to serve as flags (fig. 24, p. 53).

To all animals, the menu of whose meals consists of myriads of minutiæ, they doubtless render another service. For it is known that if an electric light is let down into the surface waters, small creatures gather round in swarms, and in the depths a brilliant phosphorescent light would attract unlimited kickshaws. No doubt a light may attract enemies, an indisputable drawback. But the prizes of life are not won by those who run no risks. If the gleaming patches are indispensable to the fish as recognition marks, or as a means of discovering their prey, or for attracting minute creatures, or for all three reasons, the drawbacks must be put up with. Then there is the question of warning colours. It is possible that these brilliantly lighted fish are nauseous, and the phosphorescence may advertise the fact.

About this, I believe, nothing is known. As to deep-sea creatures and their ways it is easier to speculate than to prove.

The abyss, like the shallow water, seems to have its angler fish, who dangles over his nose, not what has the appearance of an innocent piece of seaweed — no good as a decoy in so niggardly a light—but a phosphorescent will-o'-the-wisp to lure his prey into his jaws.[1] But speaking generally we are too much in the dark as yet even to sketch in rough outline the life history of many denizens of the sunless abyss. Nevertheless it is well to keep all possibilities before us, and look for evidences for or against any suggestion that is thrown out. Of one thing we may feel sure : the fish are a fierce and predatory set. The big mouths and ferocious aspect of the majority put that beyond all doubt.

Colour

The question of light naturally leads on to the question of colour. Most of the fish are dull and uniform in hue. Still there is one that displays bright red, another is pale rose. Commoner are such colours as brown, brownish-yellow, and violet. But in almost every case the colour is dull, and there is little or no pattern. It is a very rare thing to find a fish that has any definite markings, unless they are phosphorescent patches or dots. The exceptions, and there are a few, are probably species that have comparatively recently made the deep seas their home. They still retain markings that were of use when they lived in the shallower waters. Among the crustaceans various shades of red—plain washes of colour—predominate. Of what use patterns where the light is so feeble ? As to mere colour, there is no more need to explain its existence than the absence of colour. Why has gold its brilliant hue ? It has nothing to gain by it. So we need not puzzle over the interesting fact that the eggs of some of the deep-sea crustaceans—remarkably big eggs—are a brilliant light blue.

Compensations for the blind

Many of the animals that have become blind have, by way of compensation, other means of probing their surroundings. At least one fish (*Bathypterois longipes*) has very long pectoral fins, which, probably, he is able to move forward and so feel his way.

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[1] These fish have been already mentioned, p. 53 (fig. 23)

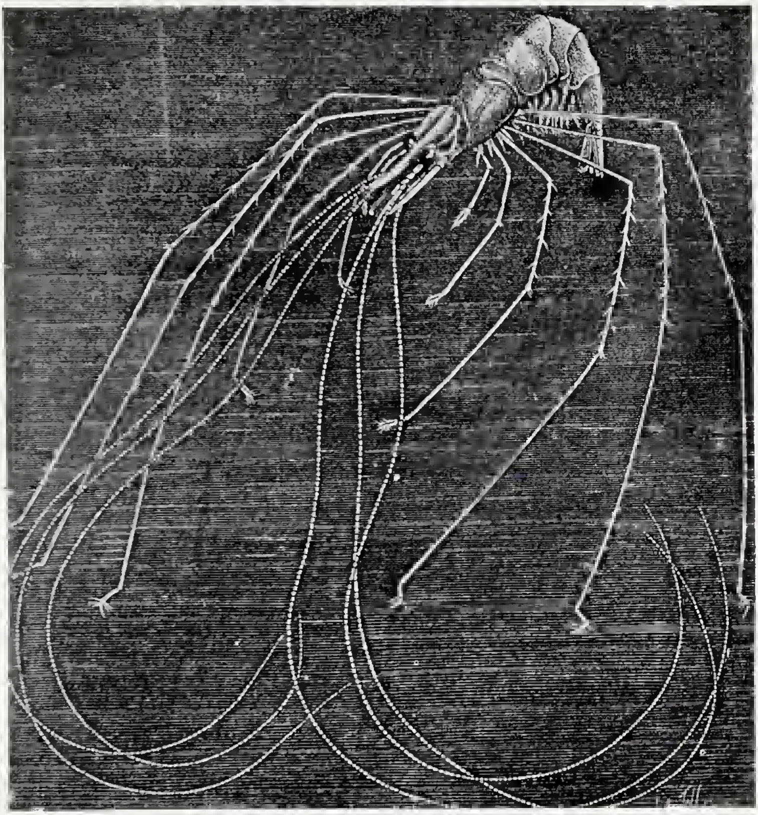

FIG. 25 (after Filhol).—Nematocarcinus gracilipes, dredged from a depth of nearly 500 fathoms off the coast of Morocco.

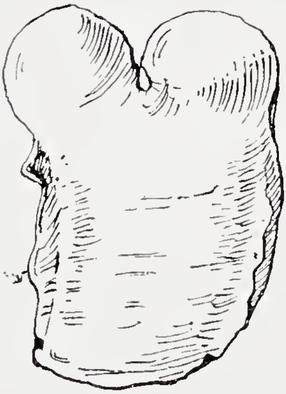

FIG. 26.—Swim-bladder of Gurnet, dividing at hinder end. Rather under half real length. Fish about 10 inches long.

Some lobster-like crustaceans (fig. 25, p. 54) have abnormally long legs and claws, so as to keep in touch with a larger circle. When sight is lost, the sense of touch finds its importance enhanced.

Weakness of skeletons

The extremely elongated appendages of some crustaceans are evidence that the currents below move but slowly. In a swift current our long-legged friend would be swept away cork-like. Another plausible first-sight inference is that lime is plentiful and easy to secrete. But that does not seem to be the case. The crustacean and the mollusc have but little lime in their shells, the fish but little in their bones. It is easy to drive a needle into the bone of a deep-sea fish. And there are no calcareous sponges. Still there are some deep-sea animals which do not suffer from deficiency of lime.

Swim-bladders

The fish of the surface waters (naturally the bottom-dwelling flat-fish do not want one) have what is called a swim-bladder. Lying above the alimentary canal and close under the backbone is a bag formed of tough membrane, sometimes in colour a beautiful silver. Generally it is a single pouch, sometimes it is partly divided into two, *e.g.* in the gurnet (fig. 26, p. 54). There can be little doubt that this organ is the homologue of our lungs. It is a pouch that originally opened from the gullet, but the opening is now usually closed up. It is filled with air that is very rich in oxygen, the air being derived from the blood in the vessels within its walls. What is the purpose of this swim-bladder? It enables the fish to float without effort, and it serves also as a bathymetric, a depth-measuring organ. If a fish ascends, the pressure around being less, the air expands and tells him what he is doing. If the ascent from the depths is too rapid the consequences may be fatal. The air expands and the bladder becomes a balloon which whirls the fish upward, till at last he appears on the surface a lifeless wreck, his stomach forced out of his mouth. Long before the abyss had been explored by the dredge and the trawl, fish, thus ballooned up to the surface, had been occasionally picked up by Portuguese fishermen. Probably the accident occurred in the heat of the chase, either the pursuer or the pursued neglecting the hints given by the swim-bladder, its inner monitor. But not only is the swim-bladder useful as enabling its owner to distinguish between up and down, between a rapid and a gentle incline, as a sort of spirit-level in fact, but when there is danger of asphyxiation the store of oxygen which it contains is drawn upon.

Worms and Molluscs

About that large and miscellaneous class of animals that are lumped together as worms, I wish merely to notice that among the deep-sea Annelids (ringed worms) some forms are blind; while others have very large eyes, the same phenomenon that we saw among the fish of the abyss. The various groups of mollusca are represented, and the cephalopods, of which the cuttlefish and the octopus are familiar examples, have large eyes.

Sedentary Animals

I pass on now to those animals which have lost the habit of free movement. They anchor themselves and wait for food to come to them, in alternating generations resuming the free-swimming life and seeking new anchorages. As I have already pointed out, the shore-waters are hugely prolific of such forms of life, far more so than fresh-water lakes, ponds, and streams. And I attributed this mainly to the fact that the sea has regular movements, tides or dependable currents, bringing a rich supply of food to these sedentary animals. I believe this to be the true explanation. This being so, it is startling to find that all classes of sedentary animals are represented in the abysmal depths. There are (1) Cirripedes, familiar to us as barnacles; (2) Crinoids, starfishes fixed on stalks; (3) Polyzoa (fig. 14, p. 36); (4) there are corals and hydroids; (5) sponges with flinty skeletons—no calcareous species; (6) Tunicates, familiarly known as sea-squirts. None of these go foraging, but they wait for their food to come to them. How is life possible to them in regions where there is good reason to believe that what movement of water there is amounts to nothing that can serve the turn of these anchored animals? Here then we are confronted with a

A difficulty

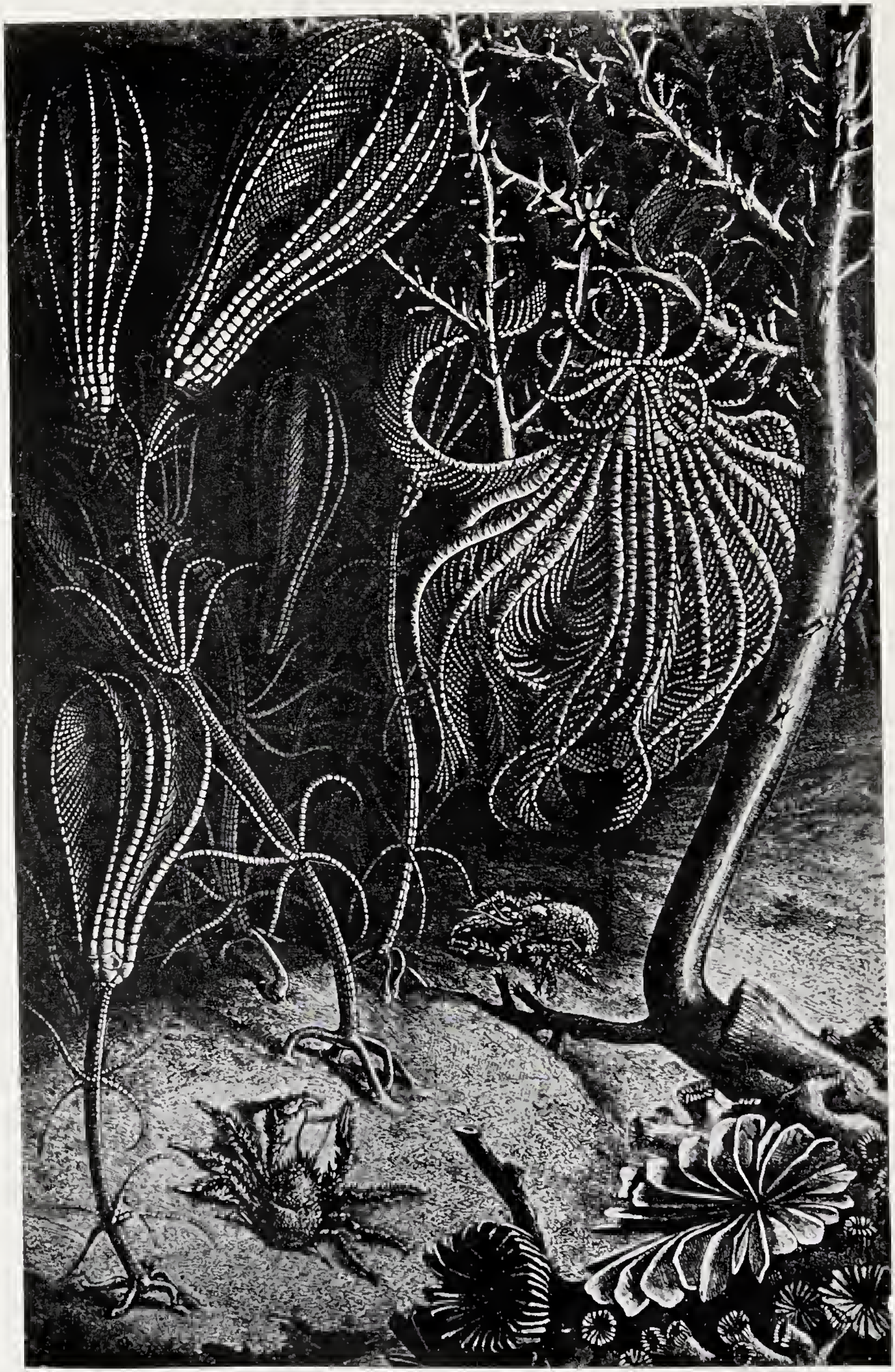

FIG. 27 (after Filhol).—Long-stalked Crinoids. On the right, corals and a tall Alcyonarian (a coral, the polypes of which have eight tentacles). Depth about 800 fathoms.

puzzling problem. Let us first survey the facts in more detail. Cirripedes were dredged by the *Challenger* from a depth of 2850 fathoms. This is deep, but not nearly the deepest. In the south-west basin of the Atlantic the greatest depth is 3450 fathoms. Evidently cirripedes are not common at the greatest depths, or some would have been brought up in the dredge or the trawl. Some Madrepore corals were brought up from a depth of 3000 fathoms. They decrease in number with depth, but as Moseley points out, the wide mesh of the trawl let many escape. Far more crinoids are found in deep than in surface waters, but there are not many below 2000 fathoms (fig. 27, p. 57). One (Bathycrinus) is found between 2000 and 2500 fathoms. Another (Antedon) ranges to 2900. Still there is evidently something that discourages them at the greatest depths. There are only two simple tunicates below 2000 fathoms. One compound tunicate ranges to a depth of 1600 fathoms. Evidently the tunicates are less at home at great depths. In fact there seems to be a decrease in the number of fixed forms of life generally with increase of depth. But the reduction in numbers does not get rid of the difficulty presented by the few, comparatively speaking, which live below the level of all quick-moving currents. Let us see whether there are any structural peculiarities which may supply an explanation. Put typical specimens of all these fixed forms together and one marked feature must invariably strike one: a very large number of them have stalks, and some of them long stalks. There are no sessile barnacles similar to those that coat the rocks on many parts of the British coasts. They are all stalked. All the many crinoids found at depths greater than 1000 fathoms have this same feature highly developed, the stalks being of great length, though not rivalling in this respect the fossil forms, some of which were mounted on stems 70 feet high. The only crinoid found in our shallow waters has no stalk at all. All the three deep-sea tunicates are stalked, though the stalks are not long. The two simple forms have peduncles three inches long or rather over, while the compound form is described as being like a small toadstool. All three differ from the shallow water form

The number of stalked sedentary animals

in a most fundamental way: they have no cilia. The ordinary sea-squirt sweeps a current of water into the inhalent aperture by means of what we call cilia, *i.e.* minute threads of protoplasm. A special line of these, sticky with mucus, catch any small things that are edible and carry them to the œsophagus. The gill slits are all equipped with cilia, which bring a current of water to the blood-vessels. The deep-sea forms have large unciliated gill slits, and no line of cilia leads to the œsophagus. Professor Herdman has suggested to me that they are able to bend their stalks and graze on any dead matter that may be found within the small circle, to the circumference of which their short peduncles can reach. How else without cilia can they get food? Their inhalent aperture is said to be muscular enough to act as a mouth.

Do the barnacles and the crinoids use their stalks in the same way? And then among the Alcyonarians, the eight-rayed corals of the abyss, is Umbellula, which is most suggestively mounted on a long pliant stalk. But there remain the Polyzoa, all the corals and the hydroids, and the sponges which, having no powers of general movement, have to sweep in their food by means of cilia, as their kin in the shallow waters do. Say that these minute waving threads can start a movement in the water that would be perceptible at a distance of one-eighth of an inch —a high estimate. There must be a good many small kickshaws in these waters if life is possible to those who have no better means of hunting than this. There cannot be nearly so much microscopic life in the depth as near the surface, for all the vegetable organisms are missing? Do these fixed plant-like animals manage to catch the débris of living organisms descending from above?

The Colonisation of the Abyss

The abyss is a cold, dark place, the temperature ranging from a little above to a little below the freezing-point. Why have any animals chosen this for their habitat, and how did they find their way there? Take the first question first. Wherever there is food, it is almost certain there will be animals there to eat it, if water and oxygen are also to be had. Now, cold and inhospitable as the abyss may appear to our imagination, all these attractions are present. When the shallow water became over-crowded, no doubt those that could not well hold their own, or which multiplied over-rapidly for their available space in the shallow water, migrated to the deep, slowly penetrating downward and onward from the shallow coastal waters. This, according to Moseley, the naturalist of the Challenger Expedition, has been the process, and certainly it is the most natural explanation. But the sea-urchins are well represented at great depths, and when we think of the slow pace at which they move—put one in a bucket and watch it protruding and fixing and unfixing its tube feet—what an idea we get of the length of time required for the accomplishment of their pilgrimage! The sea-urchins that extend to the greatest depths are nearly akin to the species that flourished in the Cretaceous period, a very distant geological epoch.[1] Through long geological ages the slug-like march downward has continued. In their youthful stages, before the shell is formed, they may float or swim some little distance. This can hardly count for much. Their swimming, by means of cilia, is of the slowest. Fish can travel much more rapidly, and they use their power of locomotion, being much given to migration. Not all those that reach the limit of depth that is described as abysmal—500 fathoms—remain in the deep water all the year round. They have periodical migrations. And the spawn of fish that live at a depth of 300-400 fathoms rises to the surface, where it hatches. After a short sojourn in surface waters the young leave the kindly light of day and descend into the darkness.[2] This habit may, perhaps, be shared by fish that live at greater depths, but clearly the bottom dwellers, three miles or more below, are there for life. They cannot, after the manner of Castor and Pollux, pass alternate days or even alternate years in the world above and the world below. It is strange enough that many of those that have colonised more moderate depths should, in their embryo days, reacting the history of the species, live in the surface waters, then as they advance towards maturity, should say good-bye to the light of the sun and bury themselves in the darkness.

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[1] See Hickson, *Fauna of the Deep Sea*, p. 103.

[2] See W. Marshall's *Die Tiefsee und ihr Leben*, p. 302. These migrations are discussed also in the Challenger report. *Deep Sea Fish*, p. xxiv.

Few if any primitive types in the abyss

When it was first discovered that the abyss had a population of its own, it was hoped that ancient forms of life might be dredged up that would bridge many of the gaps in the long ascent from the one-celled organisms up to man. There would be a great haul, it was fondly hoped, of connecting links. This hope was doomed to disappointment. The abyss is not, like Australia, a museum of ancient types. The forms of life there are similar to those that dwell near the surface, with modifications adapting them to life in the darkness. The fish are nearly all of the most modern and highly-developed types. The Elasmobranchs, the primitive order to which belong the shark and the dogfish, have but one representative at a really great depth.

I have now shown what kind of animals live in the deep and the darkness, and sketched very roughly their mode of life. From the books on the subject much more may be learnt, but still not nearly all that we should like to know. As time goes on, no doubt fresh explorations will fill up blank spaces, and at length our distant acquaintance with this marvellous fauna may become less distant, though, I fear, it can never ripen into intimacy.

Chapter III

GILLS AND LUNGS

The breath of life

All living organisms breathe, whether they are plants or animals. But plants lead a sluggish life, and it requires something more than ordinary casual observation to discover that they are breathing, absorbing oxygen and giving off carbonic acid gas just as animals do, especially as they feed by the reverse process. Their feeding obscures their breathing. But we have now to do with animals who, the higher grade of them at least, never cease to fan the flame. An animal is a furnace. Food is the fuel in the raw state. Burning is nothing but oxidation, and the oxygen for this is obtained by breathing.[1] There are furnaces and furnaces. A tortoise or a turtle is a very dull-burning one; a mammal or a bird is a comparatively fierce one. The Snapping Turtle at the Zoo would sometimes stop half an hour under water. Dr Gadow says that tortoises or turtles will sometimes sulk under water for days. A canary bird, on the other hand, even when not moving, will take close upon a hundred breaths a minute. But of these contrasts I shall speak when I come to the subject of birds and reptiles. The blood, then, of animals, whether sluggish or active, must be oxidised, and they may get the oxygen either from air or from water, giving off carbon dioxide (carbonic acid gas) in exchange. But air is much richer than water in oxygen, the gas on which all life depends. In spring water about $\frac{1}{30}$ of the whole volume is air. In sea water the amount varies from $\frac{1}{30}$ to $\frac{1}{45}$. It is true that the proportion of oxygen in this air is greater than it is in ordinary atmospheric air, for it contains 32 per cent., or even more, whereas in ordinary country air there is only 21 per cent. But this greater percentage of oxygen counts for little when we bear in mind how small is the amount of air contained in ordinary spring or river or sea water. The oxygen, without which water would not be water—it is made up of oxygen and hydrogen in the proportion of one to two—cannot be made use of by fish or other animals for breathing purposes. Only the free oxygen dissolved in water is at their service, and the amount of this, as I have said, is small.

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[1] The importance of ferment action in animal life is coming to be more recognised. I cannot go into the question here. But there is no doubt that for ferment processes a high temperature is required.

The essential thing in breathing is the oxidising of the blood. The blood, when it is driven by the pulsations of the heart along the arteries, is bright and rich in oxygen. When it returns to the heart after doing its work of oxidation, it is blue-black and loaded with carbonic acid gas. It is then pumped into the lungs —I am speaking now of the higher class of animals—and as it is there separated by a very thin, almost filmy, membrane from the air in the bronchial passages, an interchange of gases takes place. Carbonic acid is given off and oxygen is absorbed, a process depending, it is believed, not only on the nature and properties of gases. The organism being alive throughout, takes what it wants and discards what it has done with. This is what goes on when the tide of air rushes into that highly elaborate organ, the human lung, in whose sponge-like mass ramify thousands of minute blood-vessels among thousands of minute extensions of the main bronchial tubes, the tubes into which the windpipe branches. All this elaboration of machinery is very wonderful, but at present I wish to concentrate attention only on essentials, and the essence of the matter is that the minute thin-walled capillaries come into contact with the air, so that the blood contained in them sheds its carbonic acid gas and absorbs oxygen in its place.

Varieties of breathing apparatus

This being the only thing essential, we should expect to find in different animals different parts of the body used for breathing purposes. And this is in fact what we do find. Earthworms breathe through the skin, and frogs also, when in winter they are living under water. In some crustaceans the lining of the alimentary canal acts as a breathing surface. Insects have their

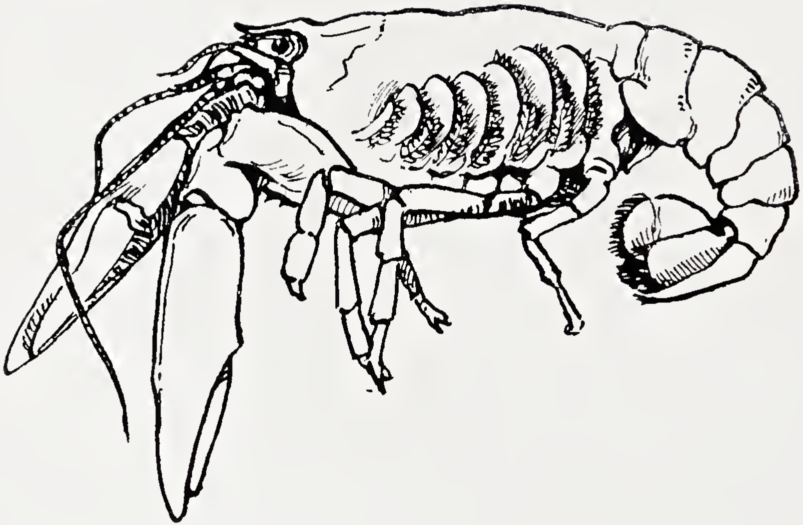

FIG. 28.—Crayfish (Astacus fluviatilis). The arched wing of the carapace, that makes a penthouse over the gills, has been removed.

Facing p. 63

tracheæ or windpipes, ramifying tubes, which take oxygen all over their bodies. The perpetual movement of a wasp's abdomen, commonly called his tail, is the outward sign that he is breathing. In other classes of animals the organs specialised for breathing come, for the most part, under the head either of branchiæ or lungs. In common parlance the word gills is used with as wide a meaning as branchiæ, meaning almost any organ whose special function is to obtain oxygen from water. As we go on it will be seen that there are many air-breathers whose respiratory apparatus acts as a lung without being one structurally. The question of structure does not limit the use of the wide term "brank" (familiar for branchia). We speak, and quite correctly, of the brank of a fish or of a crayfish. The branks of the latter are attached, some to its legs, some to its sides. The gills of a fish are attached to special bony gill arches, found only in vertebrate animals. But even the wide term brank requires occasionally to be stretched.

Consider now the course of circulation in a crayfish or lobster and a fish properly so called. In the crayfish and the lobster the blood is driven by the heart through the arteries all over the body. After doing its work among the muscles and the other tissues it finds its way to the gills, ascends and descends the delicate plumes, then goes to the heart and begins the round again (fig. 28, p. 63). In the fish the heart drives the blood first to the gills, where it is oxidised. On leaving the gills it goes on its work of oxidation throughout the body. Then it returns to the heart. The order is heart, gills, body, heart. In the crayfish it is heart, body, gills, heart. This makes it quite clear, if evidence were needed, that the gills or branks of a crayfish and those of a fish are fundamentally different organs. If they were homologous, *i.e.* of the same origin, we should expect the course of circulation to be the same. Not only does the term branchiæ cover the breathing organs of a fish and a crayfish, but those of all the molluscs that get their oxygen from the water, though special names also are used. The molluscs have a great variety of breathing apparatus. The cephalopods, the aristocracy of all the molluscs—they include the octopus, the cuttlefish, and the nautilus—breathe by means of two feathery branchiæ called ctenidia, which can easily be seen when the mantle is cut open and folded back (fig. 29, p. 64). In the whelk the bilateral symmetry is lost and there is only one ctenidium. In the snail there is a contractile chamber, richly charged with blood-vessels, beneath the mantle; in fact, as far as function goes, a lung. In the Nudibranch there are no ctenidia, and new branchiæ have been formed on the surface. The oysters, scallops, mussels have for branchiæ great flat surfaces, full of blood-vessels and alive with cilia, which keep up a current of water. Swept in through the inhalent siphon, the water passes through the gills, then out through the exhalent siphon. The molluscs, then, are some of them "air-breathers," some of them "water-breathers." The former have organs which do the work of lungs, though they do not correspond to the lungs of the vertebrate animals. The "water-breathing" molluscs can among them boast of a fine variety of branchiæ.

Comparison of gills and lungs

Let us now narrow down our investigation to the breathing machinery of crustaceans, from the crab to the woodlouse and vertebrates. The question presents itself: Which can claim priority, the "brank" or the lung? Certainly the "brank." There can be no doubt that the earliest vertebrates were water-breathers, as the lowest of the vertebrates are now. It is essential that the breathing apparatus should be kept moist. On land this requires special machinery, a small windpipe of some length opening into a chamber, closed but for this. There must be some means, too, of creating a vacuum. In mammals there is a diaphragm that can be lowered so as to enlarge the chest cavity from below. The ribs can be raised so as to enlarge the chamber in front and above. Certainly "water-breathers" require less elaborate breathing apparatus than land animals. In the water all the delicate plumelets of the lobster's gill float out and spread themselves like the leaflets of a finely divided seaweed. When dry they shrink up and collapse as the seaweed does under like circumstances. Though damp air does not give them all that they want, yet it is much better for them than dry

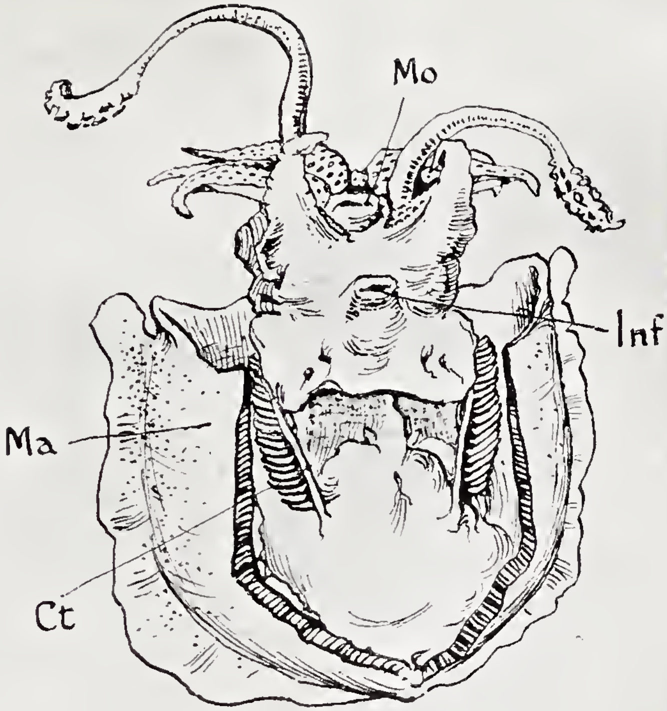

FIG. 29.—Cuttle Fish (Sepia cultrata). The mantle has been cut away to show the ctenidia (breathing organs), etc. Ma, remnant of mantle; Mo, mouth. Taking in water beneath the mantle, he drives it out from the infundibulum or funnel (Inf.), and so swims rapidly backwards.

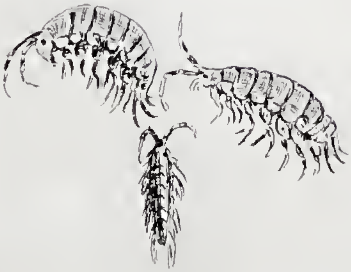

FIG. 30.—Sandhoppers (Orchestia), amphipod Crustaceans. Remarkably good "air-breathers." About natural size.

air. Some crabs are quite comfortable for a considerable time when they emerge from the water and become air-breathers. Among British species the most remarkable in this respect is the shore crab. When the tide leaves him he shelters under seaweed or makes excursions over the sand. One on which I experimented lived for fifteen days without being immersed in water except for an occasional bathe. In all he had eight bathes, lasting as a rule for ten minutes. But two of the eight were longer, one lasting over an hour, the other as long as three hours. I could not get him to eat except during his bathe. As far as breathing was concerned, I daresay he could have dispensed with bathing altogether. He was allowed about three wineglasses full of water, and this formed a shallow moat round the bottom of the jar in which he lived. The centre, being slightly rounded upward, was dry. His practice was to put the hinder end of his shell, and so of his gills, into the water and move them so as to start an upward current. But I don't think he derived much oxygen from the water, for it must soon have got used up, though the water was changed every day.[1] It merely served, I believe, to keep the gills moist. To finish this crab's history, as far as it is known to me, he was quite lively after his fifteen days, and gave me a farewell nip when I restored him to sea water. Shore crabs will live at least two days in ordinary indoor air without any water. If they escape from their tank—they are good at climbing—they wander about the room, and it is long before they succumb. I put one in a jar, half full of damp pebbles. He at once buried himself in them but was unable to find a puddle. Yet he was perfectly vigorous for several days and was then, after I had left Plymouth, restored to sea water.

The shore crab

Other crabs, dwellers in comparatively deep water, will live a day or so in damp air. But fresh water is soon fatal to them. Even the shore crab, though he extends his range up estuaries where the water is less brackish, is much better off when no water is allowed him than when he has a wineglass or two of fresh water to keep his gills damp. Land crabs have special

Crabs and fresh water

Land crabs

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[1] Possibly it may have been continually reoxidised as it passed through the gills, so that they got their oxygen from the air *viâ* the water.

adaptations for air-breathing, which presents no difficulties to them. In Ascension Island they climb to the top of Green Mountain, and sometimes steal young rabbits from their holes and eat them. In Japan they climb to a height of several thousand feet, but they always return to the sea to breed. Mr Alcock tells us that on sandbanks among the Laccadive Islands, land crabs often destroy the nestling terns by the hundred.[1] This slaughter of noble birds by animals of an inferior class is an offensive thing, reminding one of the ruin of Lydgate by his wife, an altogether lower character, in George Eliot's *Middlemarch*. But the land crab sticks at nothing. As to his special adaptations, Mr Stebbing describes the vaulting of the carapace over the gills. It is lined, he says, with a spongy membrane, retains water, and so acts as a reservoir.[2] Mr Alcock describes the lining of the gill chamber as much thickened and so enabling him to breathe air.[3] The lining is, I suppose, full of blood-vessels. But the chamber has rigid walls, so that the air cannot be expelled as it is from a lung. However, the movement of the gills, which are large, must prevent the air from stagnating. If the gill chambers were elastic and air could be pumped in and out at will, the breathing apparatus would be much more effective and the land crab would, if possible, be even more active and audacious than he is.

The woodlouse

The land crabs are certainly the most conspicuous figures among air-breathing crustaceans, but the familiar woodlouse (an isopod, "equal-footed" crustacean) is an air-breather throughout his life. He lives under rotten bark. His shell fits closely over his gills, which are attached to his hinder (abdominal) appendages, and keeps them moist. I have found woodlice near Biskra (in the northern Sahara), where the rainfall is only five inches in the year, under the bark of the stems of desert shrubs. Some amphipod crustaceans also and, notably, the sandhopper of our shores, are well adapted for breathing air (fig. 30, p. 64.)

The sandhopper

We will now leave the crustaceans.

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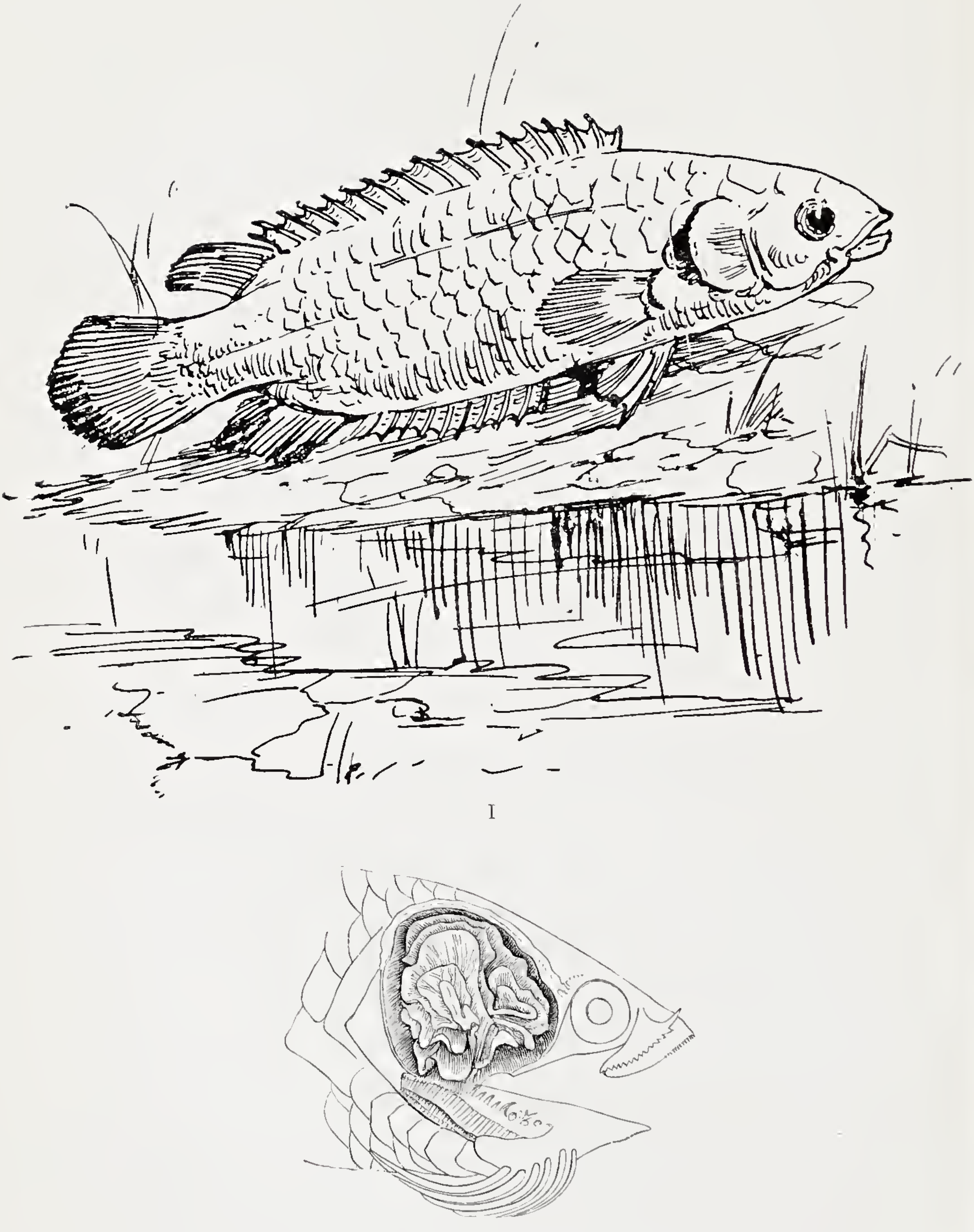
[1] *A Naturalist in Indian Seas*, by A. Alcock, p. 182, see also p. 80.

[2] *Crustacea*, International Scientific Series, by T. R. R. Stebbing.

[3] *A Naturalist in Indian Sear*, p. 80.



I

II

FIG. 31.—I, Anabas scandens, Climbing Perch; II, water-storing and breathing organ situated above the gills in Anabas (after Günther).

Breathing apparatus of fish

Among fish, too, there are not a few that can become "air-breathers" when occasion requires. There are some that have special formations by which the gills are kept damp, some that have developed breathing pouches which, though not lungs, yet do duty as such, some that possess actual lungs, and one, an oddity of oddities, that has a supplementary breathing apparatus in his tail.

The climbing perch

Almost everyone has heard of the Indian Climbing Perch (fig. 31, p. 67). Whether he does actually climb is a question. Certainly he walks across country. When his pond dries up he goes in search of another. Generally this takes place at night or in the very early morning, so that few persons have seen him on the march. We can imagine the astonishment of the Englishman who met a number of these fishes walking along a dusty road beneath a midday sun.[1] The Climbing Perch uses his strong hind fins for walking, often hitching, they say, the pectoral ones round stems of grass or other things. Over his gills on either side is a chamber from the inner walls of which project very thin plates of bone, much curled, like the valance hanging round a bed (fig. 31, p. 67). The water clinging about these plates helps to keep the gills below damp. No doubt this counts for a good deal. But probably more important is the fact that the curled plates are covered with a coating of mucous membrane that is full of blood-vessels and so capable of obtaining oxygen from the air. The everyday life of the climbing perch leaves no doubt that he is an air-breather. Every few minutes he rushes to the surface of the water, discharges vitiated air from his gill-openings and takes a nip of fresh air. When the experiment was tried of keeping a Climbing Perch from the air by stretching a net over the tank in which he lived, a little below the surface, he died asphyxiated in twelve minutes. It is significant that the swim-bladder, that versatile organ, is very large, extending far backward into the tail. For most fish it is partly a float, partly a bathymetric organ, telling its owner, by means of the expansion or contraction of the air contained in it, whether he is ascending or descending. In this latter capacity it cannot be of much service to the Climbing Perch in his shallow pond. But the air in it is rich in oxygen, and it is known that fish draw upon this resource when in danger of asphyxiation. The Climbing Perch will live from twenty-four to twenty-six hours even in dry air. The natives of India put about 100 of these little fish—some 6 inches long—together in closely-woven baskets. Thus packed close and keeping each other moist they are said to live from four to five days. This is a useful method of preservation in India, where, as soon as you have killed your fish, you must make great haste to eat him. Evidently the Climbing Perch gets oxygen from the air, and it must be the supra-branchial chamber that mainly carries on the air-breathing. How, then, does he drive the vitiated air from the chamber and introduce fresh, if, as seems to be the case, the chamber is inelastic? When he darts to the surface, probably the velocity of his rush may, on his emerging, help to drive out the contents of the breathing-chamber and give admittance to fresh air. But when he is travelling overland or living packed with others in a basket, this explanation does not apply. At such times he probably gulps air and, reducing the capacity of his mouth by the familiar frog method, drives it among the gills and into the supra-branchial chambers.

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[1] Mr E. L. Layard. See Mr Day's paper, *Proc. Zool. Society*, p. 284 (1868).

Other compound breathers

The climbing perch is by no means the only compound breather, to use a term that has been coined, among Indian fish. Indeed, compound breathers are so common that they represent at least seven families of fish. Those of the loach family are remarkable in their methods, for they pass the water from which they obtain oxygen through their alimentary canal. Its walls are adapted for breathing. Amphipnous is a very curious eel-like fish. The two pairs of fins are missing. The gill-openings are minute, and coalesce in one slit on the lower surface. There are only three gills, and these are rudimentary. But behind the head and opening into the mouth, just in front of the foremost branchial arch, are two lung-like sacs, one on each side, richly supplied with blood-vessels. They are not lungs, for they do not open into a common windpipe, and they derive their arterial blood from the branchial arteries, not from a special pulmonary artery. But they do the work of lungs. Not only the Climbing Perch but a good many other compound breathers have been experimented on in the way I have described, an experiment of the same nature as that which Surajah Dowlah or his myrmidons made when they put the English prisoners in the Black Hole of Calcutta.

Many people will be horrified at hearing that even a few fish were thus victimised. Yet no one condemns the native Indian who puts a hundred fish in a basket and leaves them there till they are on the verge of asphyxiation. No one blames the English fishmonger who leaves a lobster to die slowly in his shop window. The fact is, you may inflict almost any torture if you do it for the sake of food. The scientific experimenter is condemned, not so much because he is cruel, as because he is cruel for a trifling object, viz. to advance science! To return to this experiment. The Climbing Perch was, as I have said, asphyxiated in twelve minutes, others in times varying from one hour to twenty-four, a loach enduring the deprivation of air longer than any of the others.[1]

The experiment has also been tried of stitching a bandage round the head of the fish so as to prevent him from opening his gills and passing water through them. This seemed to cause no inconvenience.[2] It did not prevent him from rising to the surface to get air. Compound breathers left in wet grass were lively and healthy for some hours. Among those experimented on were some of the Cyprinidæ, the carp family, and it is an interesting fact that the most familiar carp, the ordinary gold-fish, comes to the top for an occasional nip of air when the water of his tank gets foul. The common carp will live for a considerable time out of water, if only it be kept damp. But Dr Günther, in his *Introduction to the Study of Fishes*, does not mention any structural peculiarity in carp that enables them to obtain oxygen from air.

A native method of fishing

Though the natives of India make no experiments with fish, they observe their habits. Mr Day quotes an interesting account of native methods of fishing in Ceylon. The scene is a swamp. Firm soil covers over two or three feet of diluted mud. A few circular patches of this soil, about three feet across, are cut away. Some of the long grass which grows on the surface is laid over the hole in two layers, one at right angles to the other. This done, the fishermen wait for the appearance of the fish. Bubbles of air coming up make known their presence. Then their noses appear, pushing through the layers of grass. It is not so easy for a fish to get back through the grass in a moment, and when he has once shown himself he is easily secured.

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[1] See Mr G. E. Dobson's paper on the "Respiration of Fresh-water Fishes," *Proc. Zool. Society*, p. 274 (1874).

[2] See "Observations on Some of the Fresh-water Fishes of India," by Francis Day, *Proc. Zool. Society*, p. 274 (1868).

The tail as breathing organ

I must now mention the strangest method of breathing that is to be found in fish. Periophthalmus Kölreuteri is a small fish found on islands in the Malay region (fig. 32, p. 70). One of its " points " is that it can protrude and retract its eyes. When the tide ebbs it leaves the water and searches for small molluscs that have been left bare, skipping actively by the aid of its ventral and pectoral fins. Professor Hickson describes his difficulty in catching it. But the most astonishing thing about this small fish is that it can breathe with its tail. It will remain long with only its tail in the water, and this region of its small person is found to be specialised for breathing purposes, being amply provided with small blood-vessels close to the surface. It has a supplementary gill or "brank" in its tail!

Fish that have lungs

I now pass on to the Dipnoi, the fish that have lungs as well as gills. The lungs are the same organ as the swim-bladder with which most fish are equipped. The swim-bladder lies close under the backbone. It is a pouch, opening usually from the back of the gullet, but in some fish it opens from the right or left, in others from the front or ventral side. It is important to notice that it does not always open from the back, because, were this the case, it would be difficult to see in it the organ from which lungs have developed. Lungs, whether in amphibians, reptiles, birds, or mammals, are a divided pouch opening from the ventral side of the gullet. The swim-bladder opens usually from the back, but the number of exceptions forbids us to dissociate it from lungs on this ground. Very frequently the aperture closes up, and the highly oxygenated air found in the

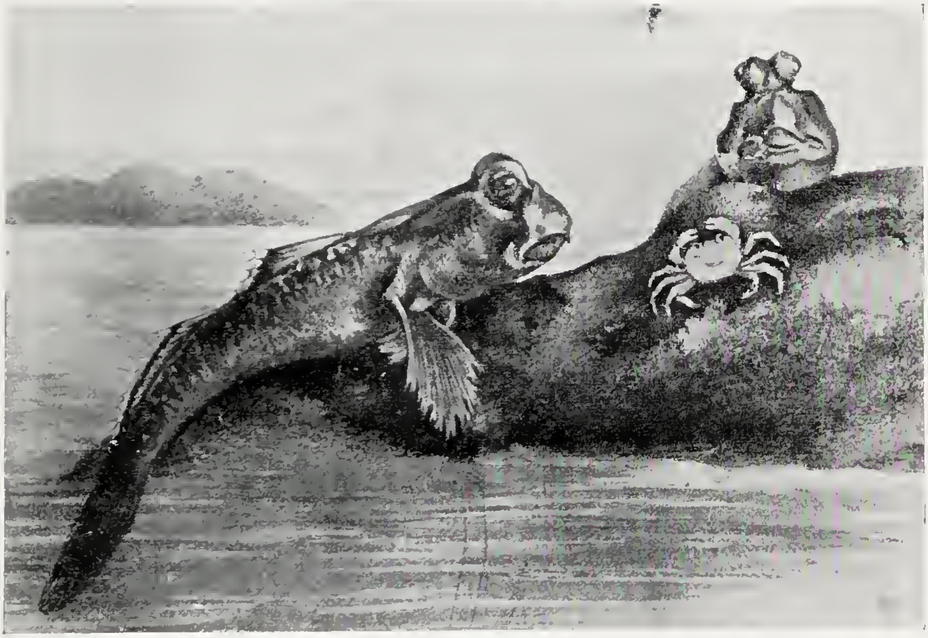

FIG. 32 (by the kind permission of Professor Hickson).—Periophthalmus kölreuteri. Tail specially modified for breathing. Very active; jumps mainly by means of its "bent muscular pectoral fins."—*Naturalist in N. Celebes*, p. 30, by S. H. Hickson.

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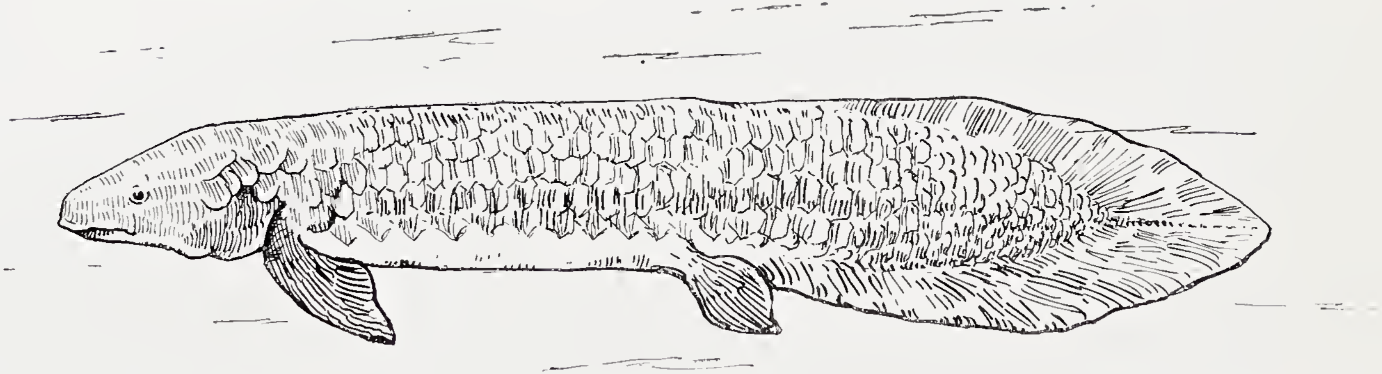

FIG. 33.—Ceratodus forsteri, Australian Lungfish. Said to attain length of 6 feet.

bladder is derived entirely from the blood-vessels which ramify in its walls. The part played by the swim-bladder in the life of the fish I have already explained. As a rule, the bladder is a single pouch, but in the gurnet it shows signs of dividing (fig. 26).[1] In the Dipnoi the bladder has become definitely a lung or pair of lungs, obtaining oxygen from the air and supplied with blood by a special pulmonary artery.

Ceratodus, the Mudfish of Queensland, is familiar to all who have visited the reptile house at the Zoo (fig. 33, p. 71). It grows to a length of 4 or 5 feet and has an undivided lung. Its gills are well developed and it is quite capable of obtaining its oxygen from the water if oxygen is there in plenty. But when the water becomes foul it can resort to air-breathing. South America and Africa have also their mudfishes, South America being represented by the Lepidosiren, and Africa by Protopterus. Each of them has a divided lung, or, as we usually put it, a pair of lungs.

Protopterus has been very minutely described by Mr W. N. Parker.[2] Specimens, the longest of which measured over 2 feet, were sent to him from the Gambia in West Africa packed in earth. Even when supplied with plenty of food they were very fond of biting pieces out of each other, often with fatal results. When badly wounded, they often lived for several days, so great was their vitality.

The lungs very much resemble those of snakes, being thin bags with blood-vessels ramifying thickly in the walls. But the anterior region, before the division into two takes place, is filled up with a sponge-like mass. In this part, therefore, it shows a higher development than the lung of a snake or a frog. Towards the hinder end the lungs get gradually more thin-walled, resembling in this those of snakes and lizards, the posterior part of which is a mere membranous bag with very little to show in the way of blood-vessels. The lungs being so efficient, we might expect the gills to be much reduced, and this is what we do find. The first and second branchial arches bear no gills, but the hinder ones have lamellæ which carry on respiration.

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[1] P. 54.

[2] *Trans. Royal Irish Academy*, vol. xxx. p. 109.

Protopterus once had lungs for his second string. Now they are his first. He comes to the surface to breathe at short intervals. At the beginning of the dry season Protopterus burrows about a foot and a half in the ground, and by means of a secretion from glands in his skin forms a cocoon. There he remains coiled up, living on fat accumulated chiefly about his tail. The saying of the negroes that he consumes his own tail is not so wide of the mark. In the same way the tadpole, when turning into a frog, uses the fat of his tail to build up his new tissue, and so he becomes a tailless Batrachian. The salmon in fresh water lives on his own accumulated fat. As to breathing, Protopterus leaves a hole in his cocoon and through that obtains air. He is believed to be remarkably long-lived. Torpid in his cocoon for five months of the year, he does not wear himself out. But he is evidently very active in the water.

The tadpole

The Dipnoi are to most people unfamiliar creatures. Europe has none to show. But that a "water-breather" should develop lungs ought not to seem strange, for it is part of the metamorphosis that every tadpole goes through when he becomes a frog. But there is this difference that, whereas Protopterus retains his gills, reduced in size and importance it is true, the tadpole, on his promotion to the higher life of his maturity, sheds his gills altogether and trusts to his lungs alone.

The axolotl

Among the Amphibians there is one which sometimes keeps its gills throughout life while having lungs available should the need for them arise. It is the Mexican Axolotl which enjoys this distinction (fig. 34, p. 72). Other species of the genus Amblystoma and, apparently, also the representatives of this same species elsewhere than in Mexico, mark the transition from the larval stage to maturity by shedding their gills and developing lungs in the orthodox amphibian fashion. But in the lake near the city of Mexico, the Axolotl, like grown men dressed in Eton collars, keep their gills throughout life. Formerly they were regarded as a distinct species and the name Perenni-branchiata (permanently gilled) was invented for them. But some that were kept in a tank in Paris in 1865 dropped their gills (external frills, that cannot escape notice) and at length revealed the secret. The

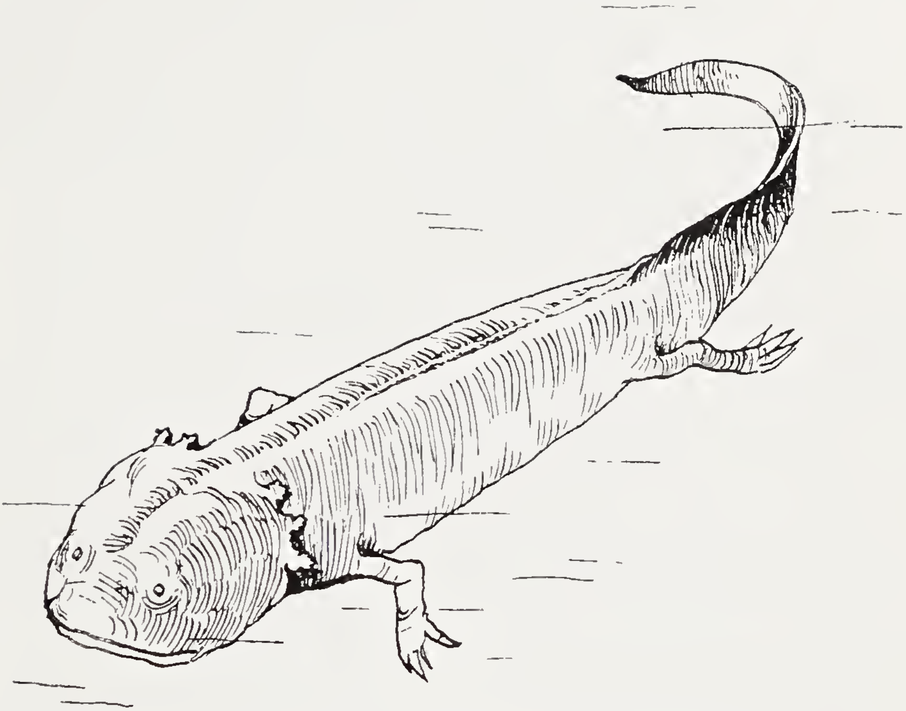

FIG. 34.—Axolotl, drawn from a specimen about 6 inches long. External gills easily visible.

Facing p. 72

Axolotl was nothing but Amblystoma, a near relation of the Salamander. In Mexico it remains all its life a larva in outward form, bringing forth its young while it is still in appearance immature. Other Axolotls were supplied with the means of emerging from the water, with the result that they too developed lungs and became Salamander-like. I once kept an Axolotl for some months. He throve on earth-worms. As an experiment I put him one afternoon on some damp earth in a vivarium. Next morning at about 11 o'clock I put him back in his tank. He swam about with great activity, but a few hours after he was dead. It may be that the change from water to air was too sudden, or the cold may have been fatal to him. It was towards the end of October.

Gill arches in embryo birds and mammals

Even birds and mammals in a very early stage have in their anatomy clear proof that they once breathed by means of gills. The bird within the egg, the young mammal before birth, have gill arches and gill slits clearly visible, though no functional gills. They recapitulate, each individual in the course of his development, the evolution of his species, though with gaps, with abbreviations, and insertions. In spite of all this tampering with the text, much of the history is decipherable, and the story of the gills is written in unmistakable language.

The human lung

Now would be the place to speak of the reptile's lungs and of the lungs of birds. But I put that off for later chapters. Of the human lung, typically mammalian, and its merits, I will now say something. It is a sponge-like mass in which thousands of minute, very thin-walled blood-vessels (capillaries) run about amid thousands of minute ramifications of the main bronchial tubes into which the windpipe branches. A great amount of blood is thus brought into contact with the air. Here is merit No. 1. Then there is its wonderful elasticity—a large proportion of the contained air is rhythmically driven out and fresh air drawn in. The diaphragm is lowered, the ribs are raised, and in rushes the vivifying current. Then, another important point, the small size and the considerable length of the tube that forms the entrance to the lungs check evaporation and help to keep them moist. But if all the air were squeezed out (let us imagine that a possibility) no length or smallness of windpipe would be of much avail. When we do our utmost and exhale all we can, still much stationary air remains. The "tidal air" rushes in and at once interchange begins between it, rich as it is in oxygen, and the stationary air that is loaded with carbonic acid gas. Only by this interchange of gases can we clear the remote passages of the labyrinth. But if all the air were breathed out, the delicate membranes would be withered by the dryness or the cold. And so we find in the human lungs three great excellencies. They oxidise a great amount of blood rapidly. They are very elastic. They are protected from drought. The lungs of mammals and birds are Nature's masterpieces. In the lower forms we see her preliminary studies.

Recapitulation

Now to recapitulate somewhat hurriedly, like the individual running over again the history of the species, except that I shall keep clear of insertions and additions. We have seen the primitive system of unlocalised breathing through the whole extent of the skin pass away, and some special apparatus, some form of branchiæ, take its place. But "water-breathing" was impossible for the higher forms of life. Free oxygen in water is small in amount. An animal that has to keep up a uniform temperature by burning up his tissues rapidly, when the weather is cold, wants oxygen in plenty to make his furnace burn brightly. He can get it only from the air, and for this purpose he must have a sponge-like lung full of ramifying blood-vessels, not a mere bag like the snake.

And so we have passed in review a number of animals with very diverse systems of breathing—the earthworm whose skin is his organ of respiration; the crayfish and his allies, with branchiæ attached to their legs and sides; the molluscs, with methods too various to recapitulate; fish, most of them content with "water-breathing," but not a few of them nipping oxygen from the richer air above; then the tadpoles and the frogs, and the axolotls, and so (postponing reptile and bird for future consideration) on to the mammal.

Chapter IV

REPTILES AND THEIR KIN

Difficulties of definition

Everyone has some more or less clear idea of what a reptile is. He can conjure up before his mind a crocodile, a tortoise, a lizard, a slow-worm, a snake, and after the manner of an impressionist painter, form in his mind a generalised picture of a reptile. But a definition is an altogether different matter. For that we want certain characteristics or combinations of characteristics which are found in reptiles only. Armed with these, we can answer questions that would otherwise be awkward, *e.g.* Why is a frog not a reptile? How does a bird differ from a reptile?

Here is a formula—A reptile is a cold-blooded back-boned animal covered with scales, that breathes throughout life by means of lungs. An amphibian (a frog for instance, or a newt) is also a cold-blooded back-boned animal, but its skin is soft and damp and it passes through the familiar tadpole stage, during which it breathes by means of gills, before it attains the superior breathing apparatus of lungs. How does a bird differ from a reptile? It is warm-blooded (*i.e.* maintains itself at a uniform temperature however much the thermometer may rise or fall) and has a covering of feathers.

This seems definite enough, but when we divide neighbouring countries with sharp definite lines we often misrepresent the facts. There is disputed territory, a borderland of uncertain ownership, which those who know it best hesitate to assign to this country or to that. These difficulties constantly occur in zoology when we try to map out animals into their different groups. When we say that reptiles are cold-blooded and birds warm-blooded, certainly we have hit on one of the best dividing lines. But even here there is no absolute sharpness of definition. A python at the Zoo once incubated, sat or lay upon her eggs for six

A warm-blooded python

weeks, and once during that time her temperature, taken by means of a thermometer laid between the folds, was 16.7 higher than that of the surrounding air, while even that of a male python in a neighbouring compartment where the conditions were the same was only 5 degrees lower than that of the female. The systematist, whose business it is to arrange animals and plants in groups, likes exactness of definition, but Nature dislikes it.

Scales and feathers

Temperature, in spite of the python, supplies as good a dividing line as we are often likely to get. Again, a coating of scales distinguishes reptile from bird. True, a feather is only a glorified scale. But then it has been glorified till it is no longer a commonplace scale, or even comparable with one. Even the small, at first glance scale-like, feathers of the penguin are distinctly feathers. Our difficulties are greater when we try to mark off reptiles from amphibians. Reptiles have scales, we say, and amphibians have none.

Pterodactyles

But the Pterodactyles, the winged reptiles, that in the secondary period of geology were kings of the air till birds dethroned them, had no scales. At any rate the rocks have preserved no trace of them, and the lithographic stone of Bavaria that shows us in detail the feathers of the most ancient of birds, Archæopteryx, would hardly have failed completely with reptilian scales. Many specimens of Pterodactyles have been found in it, and in no case is there of scales even a trace. We must, therefore, decide that they did not exist. Now to proceed to our second standby. Amphibians pass through an aquatic stage, during which they breathe by gills, before their lungs develop and they become terrestrial animals. But here too an awkward fact crops up.

A frog springing from an egg

Mr Guppy writes of *Rana opisthodon*, a frog which he discovered in the Solomon Islands: "During a descent from one of the peaks of Faro Island I stopped at a stream some 400 feet above the sea, where my native boys collected from the moist crevices of the rocks close to the water a number of transparent gelatinous balls rather smaller than a marble. Each of these balls contained a young frog, about four inches in length, apparently fully developed, with very long hind-legs and short fore-legs, no tail, and bearing on the sides of the body small tufts of what seemed to be

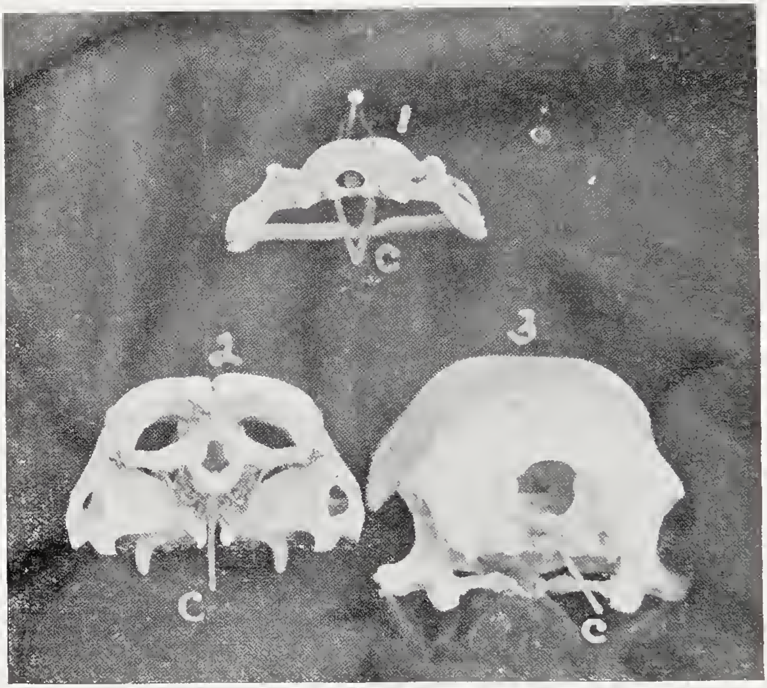

FIG. 35.—Skull of—(1) Frog; (2) Lizard—Uromastix; (3) Eagle. C, condyle.

Facing p. 77

branchiæ (gills). On my rupturing the ball or egg in which the little animal was doubled up, the tiny frog took a marvellous leap into its existence and disappeared before I could catch it" (*Trans. Zool. Soc.* xii., 1884, p. 51). And this instance does not stand alone. Other Batrachians are getting through the larval stages within the egg, *i.e.* they are removing the most essential difference between themselves and reptiles. For what have reptiles done but suppress the larval stage, the gill arches being present in the embryo within the egg but never becoming functional, never being used for breathing? But though Rana opisthodon and others thus bridge the gulf between reptiles and Batrachians, there remain other points of difference, so that a frog born as a frog from the egg is after all an unmistakable Batrachian. To take one, and that the clearest and most dependable. Batrachians generally have two condyles at the base of the skull—rounded surfaces which rest on the first vertebra of the backbone (see fig. 35, p. 77). It is on these condyles that the head turns when it is moved from right to left or up and down. All existing reptiles have, like birds, only one condyle, situated in the middle, and fitting into a hollow in the first or atlas vertebra. Here, then, is a character which separates all Batrachians from all reptiles—or rather all existing reptiles, for the bones of certain fossil reptiles called Theromorpha have been discovered in Bohemia, in Russia, in Scotland and, notably, in South Africa and North America, in which the condyles vary from one to three. Some have the two condyles that were held to be the speciality of Amphibians and Mammals. Not only are these Theromorpha (*i.e.* mammal-like creatures) very notable among reptiles for their condyles, but the higher forms of them have, not the teeth of reptiles, all very similar to one another in build but, teeth differentiated into incisors (the front cutting teeth), canines, and molars (or grinders), with many cusps. These ancient Theromorpha, big beasts some of them, with skulls a foot in length, thus bridge the gulf between reptiles and mammals and supply good ground for the belief that mammals have sprung from reptiles. But these particular Theromorpha cannot have been in the direct line, for their geological history

Skulls of reptiles and batrachians

Mammal-like reptiles

extends from the Permian period on to the Triassic, and in the Triassic there were already mammals upon the earth. At an earlier date these mammals must have sprung from simpler forms of Theromorpha, of which as yet no remains have been discovered by geologists. Before leaving them, let me briefly survey the question of condyles. The reptiles with their one condyle are believed to have originated from the Batrachians that now have uniformly two. But a particular group of reptiles (the old Theromorpha) have a varying number—one, two, or three—and a primitive form of these gave rise to the two-condyled mammals. There must have been a time of variableness when the ancestors of amphibians and reptiles had not crystallised into very definite forms, a time of kaleidoscopic shifts from one to two or three condyles, till at last stability was reached and well-defined classes were formed.

A definition

We now know how to define a reptile. It is a cold-blooded animal (with an occasional tendency to warm-bloodedness) covered with scales (if we neglect the extinct Pterodactyles) with one condyle at the base of the skull (keeping out of sight for the moment the Theromorpha who have one, two, or three). Since Nature abhors definitions, we must not complain if she does not allow us a better one than this. And now that we have got the reptiles all into one pen and shut out the Batrachians and the birds, we may examine our herd. How miscellaneous they are! What can be more different at first sight than a stiff-backed tortoise and a pliant, writhing snake? How unlike a typical lizard is to either! Even among lizards, what differences there are, for the slow-worm looks most unlizard-like, in fact like a snake, and yet if we see his skeleton, his breast bone forbids us to call him one. Then there is the crocodile so like a lizard, but with a heart that compels us to put him and the other alligators in an order by themselves. And there is the New Zealand Hatteria or Tuatara whose ribs have projections (uncinate processes) like a bird's. He is very much like a lizard, but, if we call him one, we do so in defiance of anatomy.

Wide differences between reptiles

Here, then, are no less than five orders or sub-orders presenting very great differences in anatomy and habits. But, after

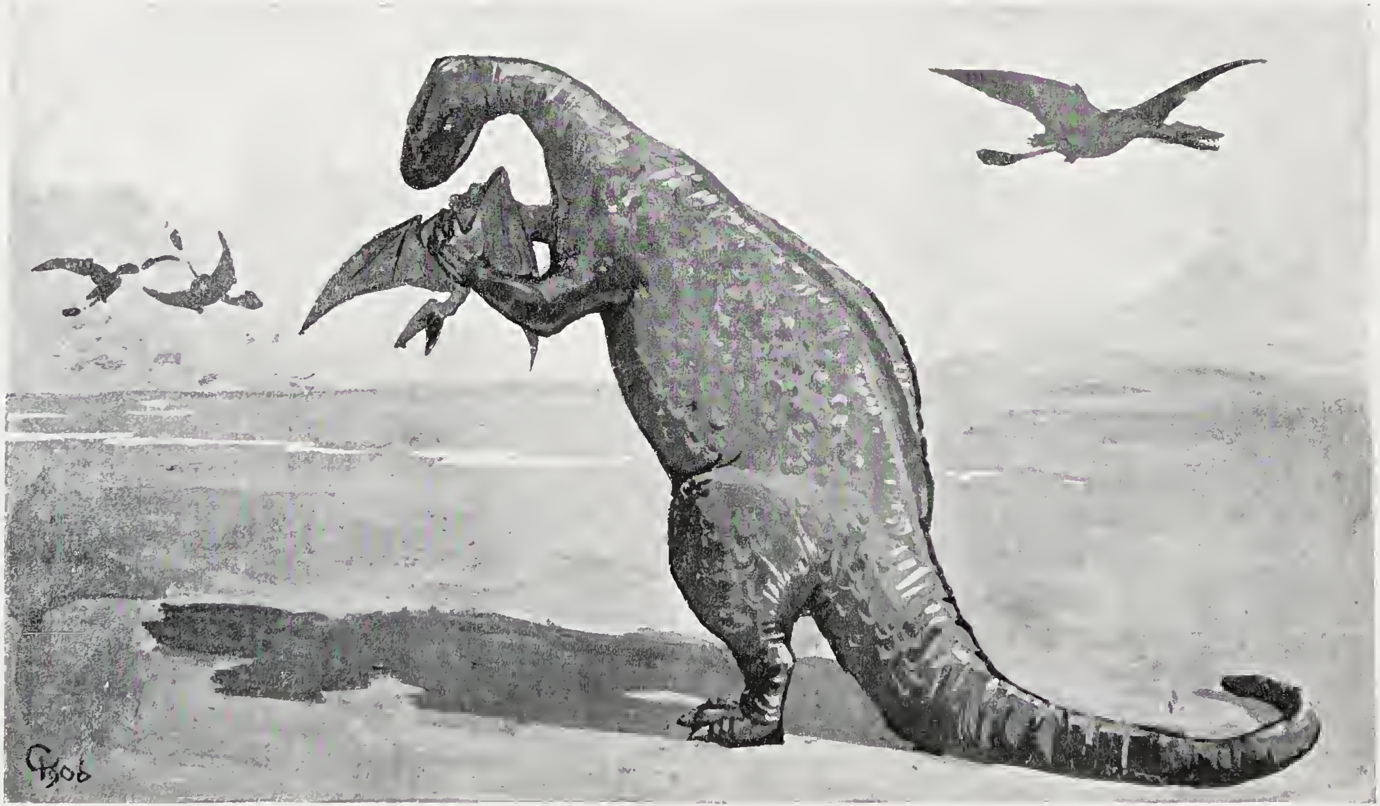

FIG. 36.—A Dinosaur devouring a Pterodactyle. The leaf-like expanse at the end of the tail distinguishes Rhamphorhyneus.

Facing p. 79

all, we have in our pen only a small fraction of the sum total of reptiles. The existing representatives are a mere remnant of a once multitudinous assemblage. Consider the strange forms that would appear on the scene, could we only reproduce those that have passed away, that lorded it on the earth in the secondary period. The Theromorpha, lizard-like at first sight only! The Plesiosauris with their long necks and fin-like limbs, and the short-necked Ichthyosauris! The Dinosaurs, with legs like a bird's and with a tail as powerful as a kangaroo's! The Pterodactyles or Ornithosaurs, that winged the air like enormous bats! (fig. 36 and 37, pp. 79 and 80). Here are five more orders, each with a very marked character of its own, now no longer represented among the living animals of the earth.[1] Everything tends to show that reptiles have had their day. Mammals and birds are the dominant classes, and the reptiles that are left keep near their holes or near the water, and nearly all of them run for their lives when an enemy appears. Mr Boulenger counts 264 species of snakes in India, of lizards 225. Of neither a very great number. Of alligators there are but 3. Of Chelonians (turtles and tortoises) but 43, of Chamæleons but one.

Existing reptiles a mere remnant

True, there are on the earth (see Dr Gadow's *Amphibia and Reptiles*, p. 4) 3500 species of reptiles, but of birds which are modernised reptiles that have supplanted the old-world forms, there are over 10,000. Of mammals, whose claim to the first place is unaffected by their small number of species, there are 2700. The early vertebrate period was the heyday of fishes and Amphibians. Reptiles then obtained the overlordship till mammals and birds, advancing at first in a small and unpretentious way, rose to the top and have ever since divided the best things of the earth between them.

In all these orders of reptiles, easily distinguishable most of them not only by the man of science, but by the most casual observer, what is it that, having once been similar in all, has varied and caused such divergence? For if there is anything in the modern theory of evolution, all the diverse forms have sprung from some one stock, or, possibly, from two or three very similar stocks, much less specialised, having no armour equal to that of the tortoise, but little of the serpentine power of the snake, and with no power of flight like the Pterodactyle. We are apt to imagine that bones are the part of the body that will vary least. They suggest solidity and permanence. And yet compare the backbone of a tortoise bereft of all pliability, the spines of its vertebræ expanded into plates, and these plates fitted together with others that are rigidly fused with its ribs—compare this backbone with that of the snake, which yields in suppleness only to the neck of a bird. And what has become of the legs of the snake? We are inclined to say *perierunt etiam ruinæ*. But the python does retain vestiges of the hind legs, just the nails appearing through the skin. Take, then, the lizard, the snake, the tortoise, at first sight the most divergent of existing forms, and it is the hard parts (the bones) that have varied most.

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[1] See note at end of chapter.

Variability of the skeleton

Conservatism of the soft parts.

The lungs

There is far less variation in the soft parts. But first, I will mention an exception. There is a great difference between the lungs of lizards and snakes on the one hand, and those of the tortoises and turtles and crocodiles on the other. In the case of the former, the lung is a mere bag, the hinder part (in most cases at any rate) formed only of a membrane with hardly any blood-vessels in it. In the tortoises and crocodiles it is much more complicated, being divided up into a number of chambers. In the Chamæleon there are pockets or pouches opening from the lungs that remind one, though only as a musket may suggest a big gun, of the capacious airsacs of birds.

The heart

The lungs, then, have varied, and cannot be quoted as showing the extreme conservatism of the soft organs of the body. On the other hand, there is a typical reptilian heart, common to all existing orders except the crocodilia. To make clear its nature I must describe it at some length. But, first, I will briefly sketch the structure of the more perfect hearts that have been developed in mammals and in birds. The bird's heart and the mammal's have four chambers. Between the two on the left and the two on the right is an impassable division, whereas the two left-hand chambers communicate by means of an opening, as likewise do the two on the right (fig. 38, p. 81).

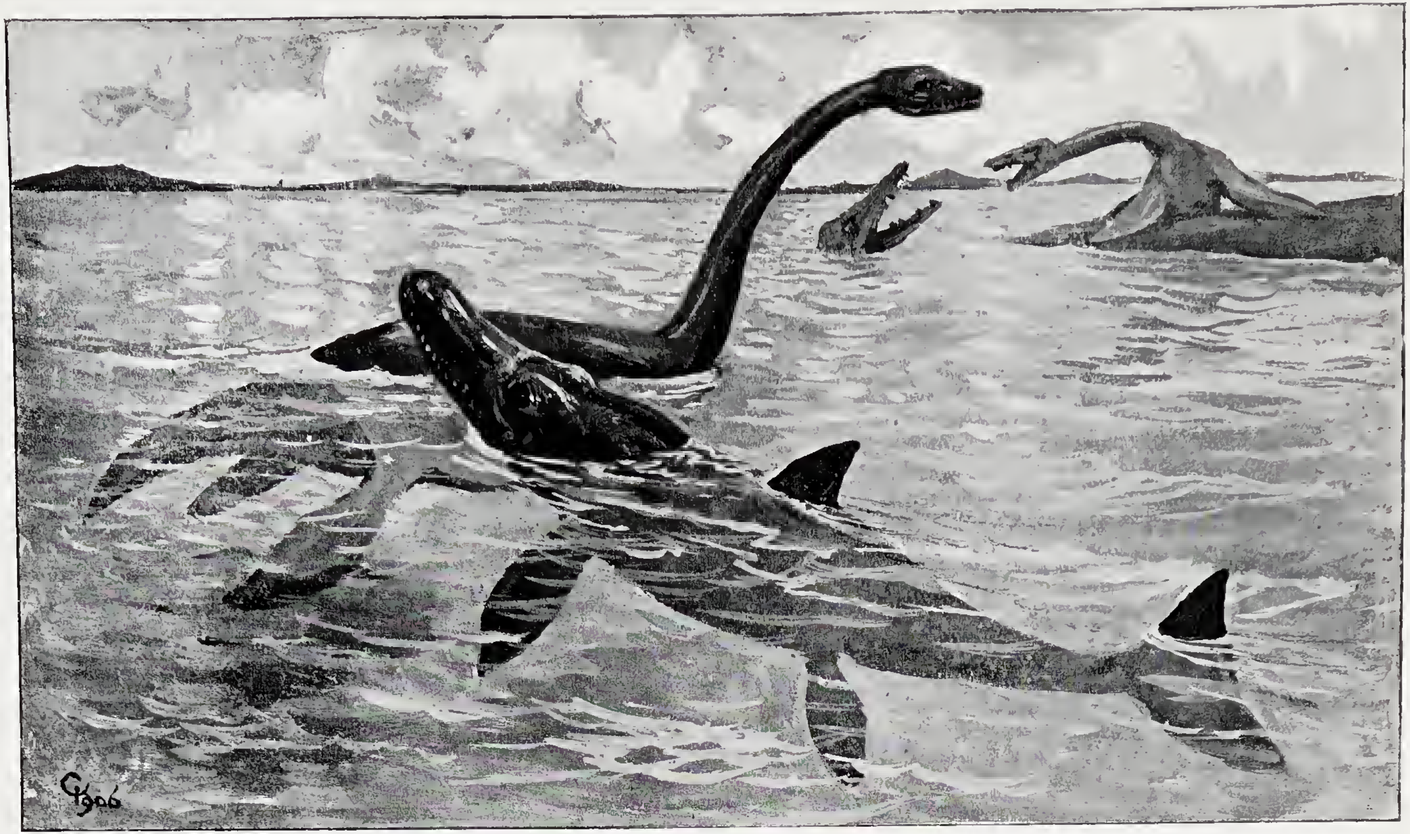

Fig. 37.—Marine Lizards, long-necked Plesiosaurs, and a short-necked Ichthyosaur. This picture gives a vivid idea of marine reptile life in the secondary period, but it does not pretend to absolute accuracy. The Plesiosaur in the centre is a little too thick in the body, and the paddles of Ichthyosaurs were rather shorter than is here represented. They, probably, swam mainly by means of their powerful tails. See note on p. 101.

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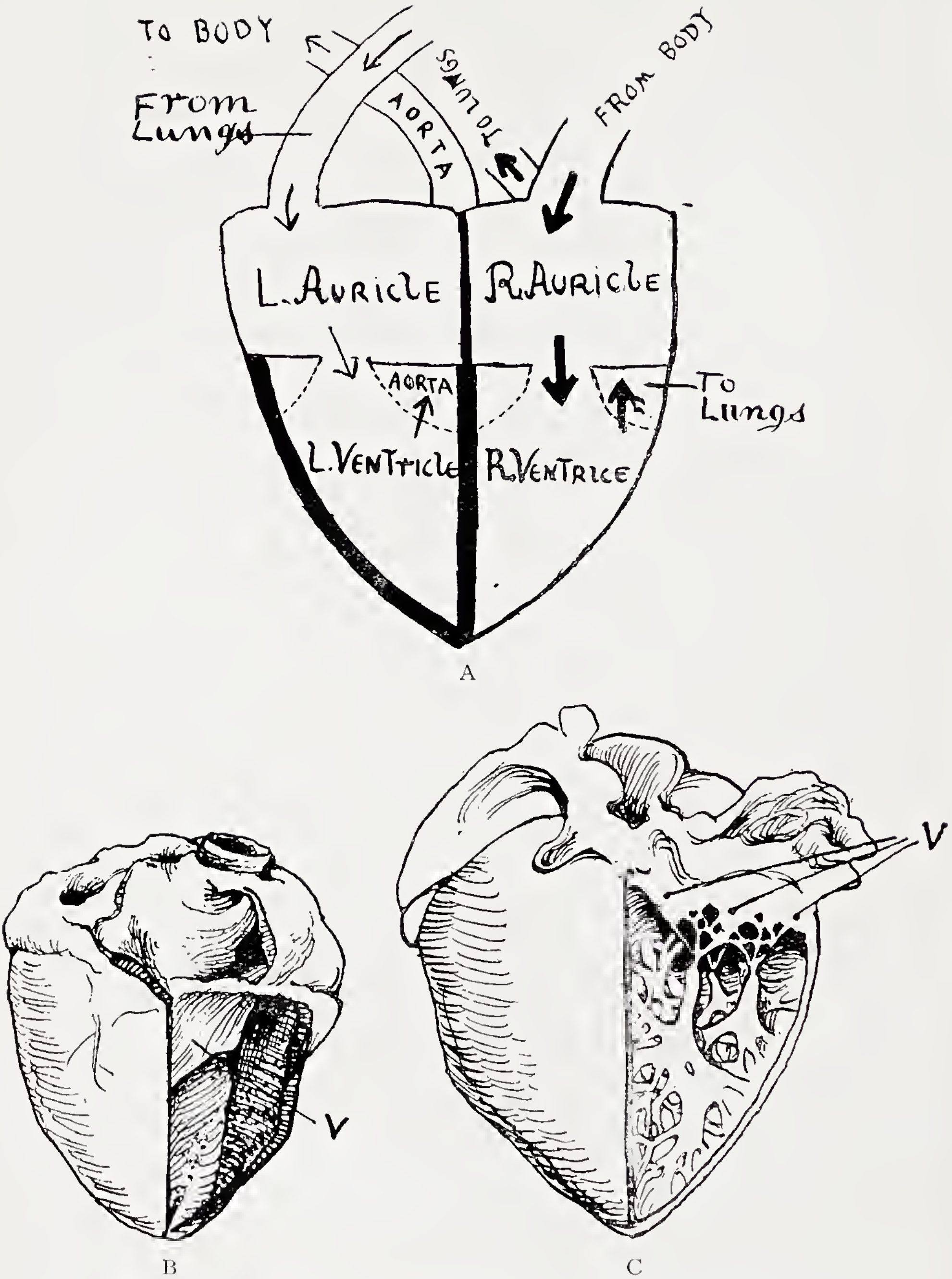

Fig. 38.—A, diagram to show the working of heart of bird or mammal. The dark arrows indicate the course of the venous blood, the light ones of the arterial. The dotted lines represent valves. B, heart of bird; C, (half real height), lower part of human heart. The right ventricles have been opened to show the valves (V).

The two upper chambers are called auricles, the two lower ones ventricles. Into the right auricle is poured the blood, when, having done its work, it returns, dark blue black in colour, from the body. Thence it passes into the right ventricle. When the heart contracts, much of it, were there no machinery for hindering it, would pass back again into the upper chamber, but this is prevented by valves. The blood, therefore, passes up the artery that leads to the lungs (the pulmonary artery). In the lungs it obtains oxygen from the air inhaled, being separated from it only by very thin membranes. The oxygen gives it a bright red colour. Thus oxidised it returns to the heart via the pulmonary vein, the only vein which carries red blood, and is discharged into the left auricle, whence it passes into the left ventricle, the valves allowing it a free passage downwards. It is now in the strongest and most muscular of the four chambers. When the left ventricle contracts, the blood, forbidden by the valves to return to the upper chamber, is sent pulsing along the aorta, the great artery whose branches distribute it over the head and body. The entrance to the aorta, like that to the pulmonary artery, is guarded by three semi-lunar valves, so that the blood may not go backward. This is the plan on which the hearts both of mammals and birds are built. Their excellence lies in this, that the venous blood is kept entirely separate from the arterial, and has no more work given it to do till it has been re-oxidised in the lungs.

Developed independently, and not inherited from a common ancestor, it is astonishing that they should so closely resemble one another, the only important difference being that the valve between the two right-hand chambers in the bird's heart is formed by a single flap of muscle, while in the mammal's three flaps of tough membrane go to its formation, and it is hence called the tricuspid valve.

To pass on to the reptile's heart (fig. 39, p. 82). The typical reptilian heart, the type common to Chelonians (tortoises and turtles), lizards, and snakes, but not to crocodiles, has the two auricles completely divided from one another, but the ventricle imperfectly partitioned into two chambers. At the base of the heart, in the turtle at any rate, is a mass of strong fibrous tissue forming a network with intervening passages, and constituting the floor of the ventricle. The septum, or partition which partly divides the ventricle, rises from this spongy foundation. But the back part of it attains no great elevation. In front, near the pulmonary artery, it reaches to the roof of the ventricle. The right-hand chamber is much smaller than the left. From the former spring the left aorta (so called because it arches over to the left) and the pulmonary artery.[1] From the left-hand chamber springs the right aorta (arching over to the right). The thin wall which separates the two auricles from one another protrudes into the ventricle, and grows out into great flaps on left and right that act as valves and prevent the blood from forcing its way back to the upper chambers. These flaps when hanging down form a second partition, incompletely dividing the left-hand chamber of the ventricle into two.

We are now in a position to explain the working of the turtle's heart. The blood is squeezed from the auricles when they contract, venous from the right auricle, arterial from the left, from both of them into the large left-hand chamber of the ventricles, but on opposite sides of the incomplete partition formed by the valves, which hang down as it rushes in. The venous blood on the right of the valves at once begins to find its way into the chamber to the right of the septum; the arterial blood at the extreme left is not only more distant, but is checked by the hanging valves. Now comes the contraction of the ventricle. The remainder (or most of it) of the venous blood is forced into the right-hand chamber. The arterial blood, forcing the valves upward so that they block the openings into the auricles, flows freely towards the septum, which, as the contraction proceeds, is forced backward till its front part, which reaches to the roof of the ventricle, comes into contact with the back wall, and the partition between the two chambers is for the time complete, or very nearly so. The result is that the right aorta carries mainly arterial blood.

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[1] The diagram of the turtle's heart in Huxley's *Comparative Anatomy* is incorrect in most important points. It is still reproduced in text-books.

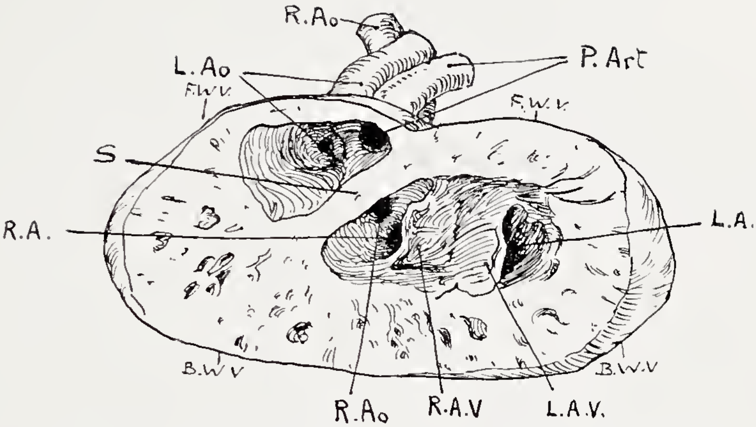

FIG. 39.—Heart of Turtle, horizontal section through the ventricle ($\frac{5}{7}$ actual breadth). Looked at thus (with the front wall uppermost), the right side appears as left; B.W.V., back wall of ventricle; F.W.V., front wall of ventricle; L.A., opening from left auricle; L.Ao., left aorta (arches to the left, springs from the right chamber); L.A.V., left auricular valve; P.Art, pulmonary artery; R.A., opening from right auricle; R.Ao., right aorta (arches to the right, springs from the left chamber); R.A.V., right auricular valve; S, septum incompletely dividing the ventricle into two chambers.

Facing p. 82

Altogether the turtle's heart, though a clumsy piece of machinery, works better than one might expect. The right aorta gives off the carotid arteries, and sends its approximation to arterial blood to the brain. The left aorta, rather smaller to start with, carrying venous blood, gives off arteries that run to the intestines, where quick movement is not so much required. It is thus greatly reduced when it joins once more with the right aorta, and the united trunk sends off branches to supply the muscles. The better blood of the right aorta predominates over the inferior blood of the left in the regions of active movement. In some minor but yet most important points the reptile's heart is highly efficient. Thus the entrances to the two aortæ and the pulmonary artery are guarded by semi-lunar valves to prevent any backflow of blood.

The heart of a crocodile is one of the strangest things in animal mechanism. It is so provokingly clumsy, and yet it has gone near to attaining the efficiency of the best types nature has produced. There is an impassable division between the right and left chambers, both upper and lower: instead of a single ventricle with a half-finished dividing wall, it has two absolutely separate ventricles. This is excellent. But the two aortæ had to be arranged for, and here comes a breakdown. One aorta springs from the left ventricle and carries oxidised blood to the body (so far good), while the other springs from the right ventricle and distributes venous blood. If that from the right ventricle could but be eliminated, a crocodile's heart would be much like that of a bird. But why this division into two separate chambers, if, after all, the black used-up blood is to be sent on its rounds again and expected to do work? And here is a very curious little point: there is a small opening between the two aortæ where they cross, and the left one (that which arches over to the left) gets the little oxidised blood it has through this small opening. But there is a fact to be mentioned which makes matters better than they otherwise would be. The right aorta (that which springs from the left ventricle and bends to the right) carries its red oxidised blood to the head and to the muscles of the trunk and tail. When the crocodile, alarmed, dashes into the water, or when he strikes his prey with a sudden swing of the tail, his alacrity is due to the oxidised blood in the active and governing parts of him. The left aorta carries venous blood, with only just a tincture of arterial, admitted through the small aperture, to most of the internal organs. There oxidation is not so important. It is the muscles that require rapidity of oxidation. It is on the brain and muscles that quickness of movement depends, and only the red blood goes to them. Still for all this the crocodile would, no doubt, be a much finer beast, had he the heart of a bird or a mammal.

So much for the hearts of reptiles. We see that there is a typical three-chambered reptilian heart shared by all existing reptiles except the crocodile.

The brain

The reptile's brain is marked by the sequence in line of the different pairs of lobes that form it. First come the cerebral hemispheres (the main seat of intelligence, so far as it exists), then the optic lobes (to which the optic nerve conveys a stimulus and where sight actually takes place), then the cerebellum or small brain, and lastly the medulla oblongata (which regulates the circulation and, in warm-blooded animals, the temperature). If we put side by side the brain of a Hatteria, the New Zealand lizard-like reptile (fig. 40, p. 84, *cf.* fig. 41), the sole representative of its order, and that of a crocodile, we shall see how similar they are, each showing the simple linear sequence, whereas in birds, reptiles themselves, but reptiles transfigured, the optic lobes are pushed to the side, while in mammals the great enlargement of the cerebral hemispheres alters the configuration of the brain. And so a reptile may be known by its brain, and, but for the crocodile's deviation from the type, by its heart. It is the bones, the firm scaffolding so suggestive of permanence and constancy, that have proved variable and plastic.

Temperature

Having now made out what a reptile is, how it differs from Batrachians on the one side and birds on the other, let us go on and consider the life of a reptile. We have already labelled them cold-blooded. This means, as I have said, that their temperature varies with their surroundings; a lizard, for instance, sinking to 40° F., say, when he lies in his hole in the

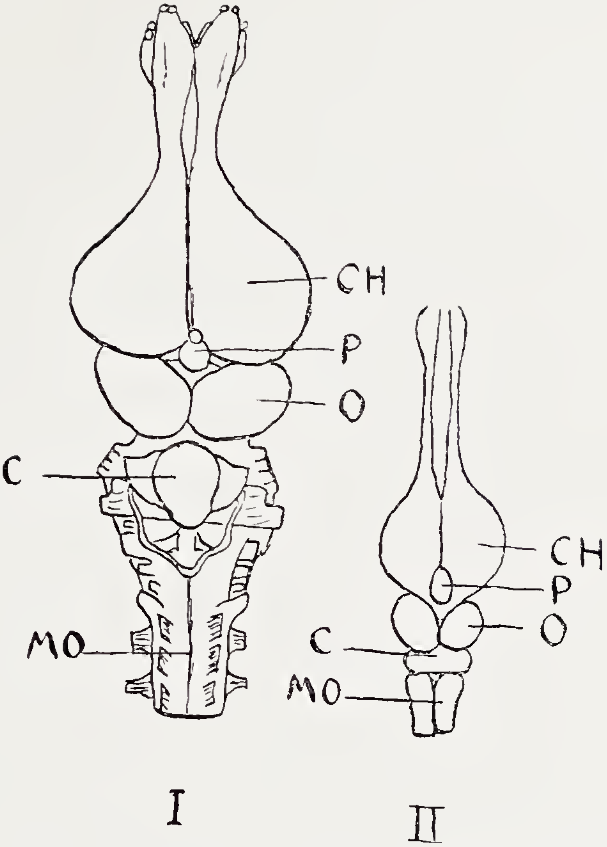

FIG. 40.—Brain of—I, Crocodile (after Wiedersheim); II, Hatteria (after Seeley). C, cerebellum; CH, cerebral hemispheres; MO, medulla oblongata; O, optic lobes; P, pineal body (vestige of central eye).

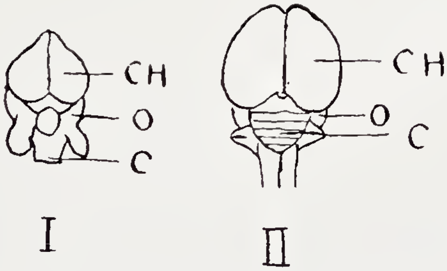

FIG. 41.—Brain of—I, Pterodactyle; II, Owl (after Seeley). There is a departure from the linear succession of the different parts. Lettering as above.

Facing p. 84

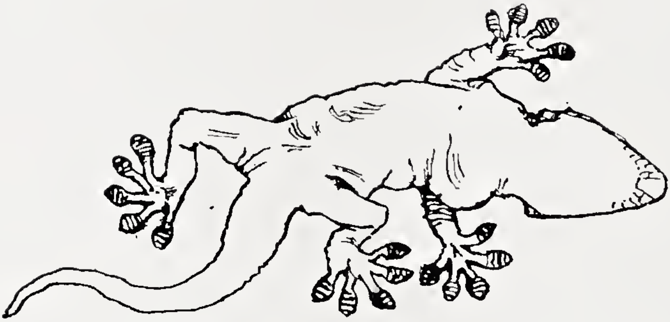

Fig. 42.—Gecko, drawn from a specimen about 6 inches long. His peculiar feet enable him to walk up vertical glass.

Facing p. 85

small hours of the morning, then rising to 80° and over when he is basking in the sun at midday. I have already mentioned a partial exception, that of the incubating python. Probably the great pythons are not alone in this; are, probably, not the only reptiles which have aspirations towards the uniform temperature of their betters in place of the up-and-down temperature usually supposed to be the only thing possible for things that creep and crawl. The difficulty of getting a reptile to submit to the use of a clinical thermometer has limited our knowledge in this direction. I managed to take the temperature of my Gecko, the little Australian lizard with rounded toes beneath which he makes a vacuum and so holds on to a wall or to upright glass (fig. 42, p. 85). His mouth was too small to close on the thermometer. I, therefore, add two degrees, a very moderate allowance. When the surrounding air was at 54°, he sent the thermometer to 60°. His temperature, I conclude, was 62°. Another day, the room being at 56°, I found his temperature to be 63°, so he is seven or eight degrees above the environing air. Here certainly is a mild tendency to an independent warm-bloodedness.

A gecko

When we know that an animal is cold-blooded, has an up-and-down temperature (poikilo-thermous is the scientific word that describes this), we know a good many connected facts. We know that his breathing is, as a rule, slow and often highly irregular, that his appetite is poor, his meals, if large, coming at rare intervals, that when cold weather comes, he torpifies, that he is often sluggish of movement, and that when active, his activity shows itself only in short spurts. that his brain power is very limited, what skill he has being chiefly instinctive, and that he never, even when young, shows any of that superfluity of energy that finds vent in play. Play develops intelligence, and a reptile has not much potential intelligence to develop.

Intervals between meals

The animal body is an engine and food is the fuel. If the fuel is very small in amount, or if the fire burns slackly, we cannot expect much in the way of horse-power. In summer time when he is at his best, a boa-constrictor will be content with one good meal a week—*e.g.* a duck or a rabbit. A crocodile in warm weather seems ready for a daily meal, but it is not, considering his bulk, much in amount. The Monitor lizard at the Zoo is, when in good fettle, obliging enough to eat an egg whenever the public are anxious to see the performance. But if kept a few days without a meal, no reptile is any the worse, even though a hot sun rouses him to his keenest appetite. Those who keep lizards need not be alarmed if the supply of food runs out and their pets go dinnerless for three or four days. Three weeks without a dinner is nothing to a boa-constrictor. The Snapping Turtle, according to Dr Gadow (*Amphibia and Reptiles*, p. 340), will go months without food. It is very different with mammals or birds. A horse must have his regular meals, no less than an alderman. A gannet gorges himself on herrings, and next day he is ready for more. How enormously the young of birds eat! When his young ones hatch out, the cock nightingale can no longer devote himself to music. He and his mate must spend their whole time in feeding their offspring. It is astonishing how much pigeons will stow away. When I found twenty-two acorns in the crop of an unusually small wood-pigeon it seemed to me worth making a note of. But in a volume of the Badminton Library (*Shooting*, p. 229) we read that as many as sixty-three have been found in a wood-pigeon's crop. But when a boa-constrictor has with effort got outside his weekly rabbit, the lump in him does not vanish for a couple of days, even though he is aided by the warmth of the surrounding air. Breathing slowly as he does he cannot have much independent temperature of his own. High animal temperature is due to the oxidation of the tissues of the body which are always in process of burning. In a bright, clear fire, oxidation is rapid. In the body of mammal or bird the process is similar though much slower. And since this burning depends on the oxidation of the blood, it depends on the efficiency of the breathing apparatus. I have already described how the blood returns, after doing its work in the various parts of the body, of a blue-black colour, having shed most of its oxygen, and how it emerges from the lungs a bright red. When it passes through the capillaries, very minute blood-vessels, in the lungs, it is separated from the oxygen of the air breathed in only by the thinnest of membranes. It gives off its carbonic acid, the waste of the body, and receives about an equal amount of oxygen in place of it. Armed with this it can carry on its work. It can burn the tissues and so generate warmth and energy. But if the breathing is slow, there is little oxidation, which means that the animal furnace is but a poor one. If a boa-constrictor is watched as he lies, the fore part of him can be seen to rise and fall three or four times in a minute, sometimes at irregular intervals, as his one long lung (for the left one is reduced to very small dimensions) fills with air. The hinder part of the simple bag-like lung does no breathing work, being mere membrane with very few blood-vessels. The air in it therefore does not get used up but passes outward again, as yet unexhausted of its oxygen, to the serviceable part of the lung. Thus both inhalation and exhalation bring fresh (or at any rate usable) air to the minute blood-vessels of the fore part of the lung, so that the mere slowness of breathing may not be quite so much a drawback as at first might appear. But the explanation of this calls attention to a weak point; the smallness of the surface (only the fore part of the thin bag of the lung) which the snake (and the lizard almost equally) has available for oxidation. Turtles and tortoises are still more sluggish in their breathing. "Sulky individuals," says Dr Gadow (*Amphibia and Reptiles*, p. 331), "remain for hours or days under water." It is a not uncommon thing for them to spend the night under water. The heat derived from without helps to put vigour into them—a tortoise will bask in the sun till he is disagreeably hot to the touch.

A reptile's breathing

Here are a few notes I have made on reptilian breathing. A crocodile I observed took twenty breaths in a minute, but when I made another count, he slackened off to eleven or twelve, irregular like most reptiles in his respiration. Another crocodile emerged from the water, having been there I don't know how long, breathed, went under again and remained under for five minutes, after which I had to go. How much longer he remained under I don't know, but I believe they often stop down much longer than this. A Monitor lizard took nine breaths in the minute; soon after, only one in a minute; then several rapid breaths. A water lizard was a little more rapid, sixteen per minute, another count giving the same rate, but some of them seemed only half breaths. A Tessellated Snake took five breaths per minute, a Garter Snake six. There seems with snakes to be a marked pause after inhalation before exhalation follows. A gecko was breathing very rapidly, sixty-six per minute, and was keeping it up regularly. He was holding on to the vertical glass of his case, so that all the movements of his under surface could be easily seen. My own gecko when I tested his breathing was very irregular, varying from eleven to forty, to fifteen. And yet his temperature was comparatively high. Possibly the gecko at the Zoo was still more above the temperature of his surroundings, but it seems unlikely, since the thermometer always stands high in the reptile house. The gecko's lungs are poor, thin bags, or else sixty-six or even forty breaths per minute would raise their temperature far higher than it seems to do. Small creatures, as a rule, breathe more rapidly, but the breathing of a small snake is only a little less sluggish than that of a big python.

Hibernation

Hibernation, as we might expect, is a reptilian characteristic. Even the crocodile in the cooler parts of his habitat torpifies during the winter. Our snakes and adders do not show themselves until the warmth of summer awakes them. Water tortoises will sometimes spend the winter in water under ice. Some tortoises æstivate, and crocodiles also, during periods of drought.

Enough has now been said to show that the reptile is not a model furnace. The fire is slack, and there is little fuel to feed it.

"Not a high-pressure engine." That is our verdict upon the reptile. But what of the actual work done? That is the next thing to investigate. Has a reptile any pace to boast of? Any last? What are his powers of defence or attack? What intelligence has he?

As to pace, no doubt reptiles are, to use a slang term, "nippy."

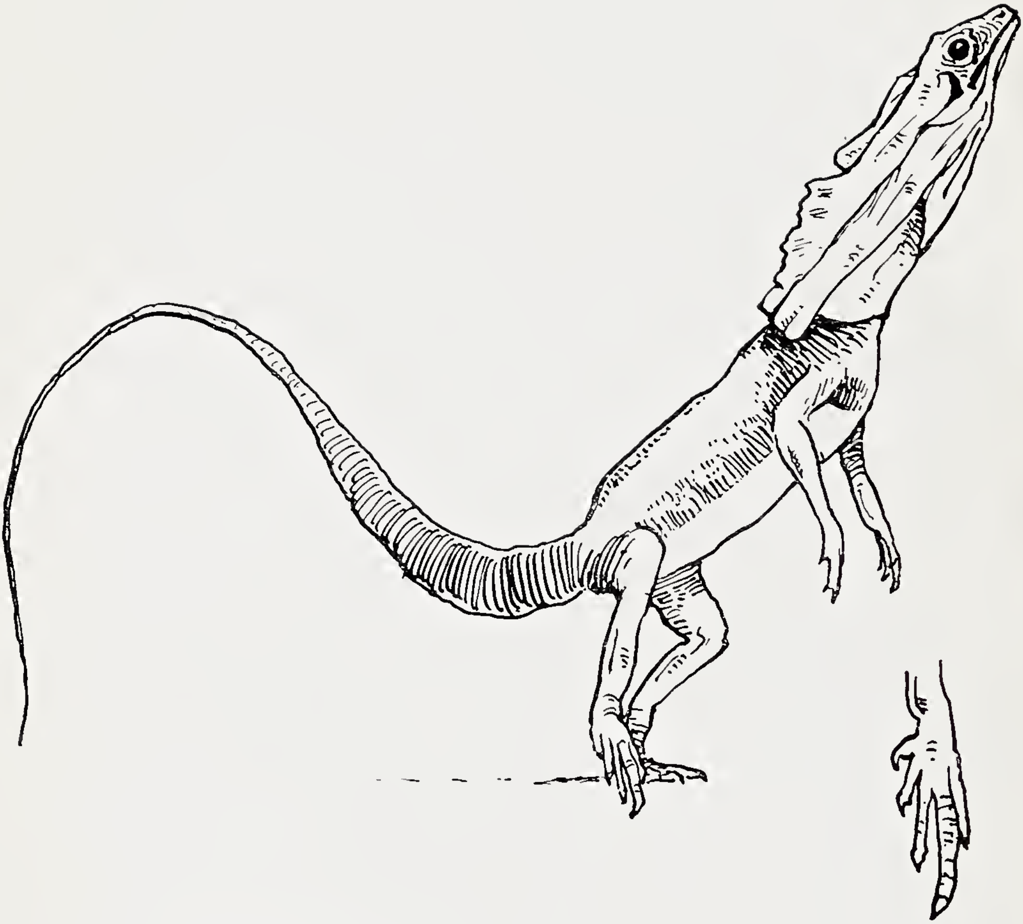

FIG. 43.—Chlamydosaurus kingi, running on hind legs. Fine specimen. Measure, with the tail, as much as 3 feet.

Facing p. 89

Pace and last of reptiles

They are good at short spurts. If a green lizard escapes in a room, it is no easy matter to lay hold of him. The geckos move with "their peculiar rushing jerks," as Dr Gadow, who holds a brief for all reptiles, puts it. But observe them closely and their pace is not so great. Walk beside a snake (a Rat-snake, *e.g.*) and it will be found that he does not get over the ground so very quickly. The common English grass snake, I have found when I have walked beside it in the open, goes less than three miles an hour. The reptile that seems to carry off the prize for speed is an Australian lizard, *Chlamydosaurus kingi*. *Chlamydosaurus* is an Australian lizard, being found in Queensland (fig. 43, p. 89). A fine specimen measures three feet in length, the tail being much longer than the body. He carries a great frill round his throat, which he probably uses for purposes of bluff, frightening his enemies by suddenly erecting it. It is connected with the muscles of the hyoid bone that lies under the mouth, and when the frill is erected the mouth is of necessity open, making, no doubt, the aspect more terrific. When he wishes to put forth all his speed, he becomes a biped. Half erect on his hind legs and tail, he goes at a great speed for thirty or forty feet at a stretch. After resting momentarily on his haunches he will continue running. So Mr Saville Kent describes his performance — describes it admiringly, with no wish to detract from its merits. Evidently the pace is considerable. Yet *Chlamydosaurus* is reptilian in his habit of constantly pausing, to take breath, I suppose. The Snapping Turtle fails in the same way. "He walks slowly, with his head, neck, and long tail extended, elevating himself on his legs like the alligator, which at that time he greatly resembles in his motions; like the alligator also, having walked a short distance he falls down to rest for a few moments, and then proceeds on his journey."[1] That reptiles are capable of quick movements cannot be doubted by anyone who has seen the chamæleon put out his tongue, half a foot or more in length, and lick up a worm. It comes like a flash of lightning. And the chamæleon, as a whole, with his deadly slow movements, is a foil that sets forth to advantage the nimbleness of his tongue. I am told that at Bombay chamæleons are kept in the boa-constrictors' cages, and remain unmolested. A boa seems to notice only moving objects. Does the chamæleon move too slowly for the boa to see him? Certainly the slowness of movement may be protective. The crocodile, it is said, moves like lightning when once he has marked his prey and prepared for his dash. The boa-constrictor very slowly approaches his duck or his rabbit, gets his range with great deliberation, then makes his dash. Quick movements these, but I have not seen or come across in reading any evidence of long-sustained activity.

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[1] Dr Gadow, *Reptiles and Amphibians*, p. 339.

It is a characteristic of the cold-blooded animals to tire quickly. The common frog when pursued starts off with long jumps, but he cannot keep it up long. The jumps soon become miserably short. A salmon when hooked holds out for a long time before he finally succumbs. But during the half-hour or so during which he is played, there are times when he offers a merely passive resistance. His sudden dashes, his great efforts, soon die away. The cray-fish swims backward in grand style, propelled by the powerful strokes of his very muscular abdomen. But though the limits of my small aquarium have not allowed me to test this well, I have heard that his strength soon gives out. He has to stop and rest. There is nothing comparable among cold-blooded animals to the feats of endurance with which we are familiar in birds. The golden-crested wren crosses the North Sea; other migrants (the American golden plovers, the Knots, the Turnstones) do enormous stretches without resting; even the homing pigeon, not so fine a flyer, covers several hundred miles without a halt. Horses dragging a vehicle behind them will cover many miles in a day. But, to return to birds, even on land their speed is great. It would be interesting to race a Peewit against a Chlamydosaurus. I am not sure the bird would not outrun the lizard. Certainly a cock pheasant would outpace him. When the Englishman exhorted his French friend not to shoot the pheasant running, did not the Frenchman reply, "No, mon ami, I will wait till he stop?"

Absence of voice

The sluggishness of reptiles, their quick starts, but want of sustained activity, I associate with their want of voice. The geckos have a cry, if we can call it so. It is described by Dr Gadow as a soft "click" produced by the tongue. I have kept one for some time, but I have not heard even this. Crocodiles have a short bark or croak, as some people describe it. They utter a kind of grunt, I should call it, when food is thrown to them at the Zoo. The snake hisses, as every one knows. But take them as a body, reptiles are very silent. Indeed, the geckos, the chamæleons, the crocodiles alone among all the number have vocal chords. Birds have risen above the reptile level and have developed wonderfully powerful and musical voices. Having great powers of locomotion, and, many of them, haunting forests and thickets, they would often be unable to find one another had they no call note. A call note, and this would seem to be the origin of their song, is a necessity to them. But reptiles are not travellers. Adders stick to their favourite haunt. One of these haunts I particularly remember: it was in Herefordshire, in an opening in a wood, the only place in the neighbourhood where any were to be found. The crocodile, it is true, will migrate on occasion, when the water courses begin to fail and the tanks become exhausted. "The marsh crocodiles," writes Sir J. E. Tennent, "have occasionally been encountered in the jungle, wandering in search of water. During a severe drought in 1844 they deserted a tank near Kornegalle (in Ceylon) and traversed the town during the night on their way to another reservoir in the suburb; two or three fell into the wells; others, in their trepidation, laid eggs in the street, and some were found entangled in garden fences and killed."[1] Other instances are on record of crocodiles migrating, and it must be owned that small, insignificant reptiles might make migratory journeys without being noticed. But there seems no evidence that they do. As a class, reptiles are sedentary. They have, in consequence, little difficulty in finding one another, especially as they haunt sunny places. Amphibians, on the other hand, are active mainly at night, and, moreover, they often travel from pond to pond. Two green frogs, kept by a friend of mine, escaped and were found near a pond almost half a mile away. They had passed by a nearer pond that lay almost in their direct route. There they woke the echoes and astonished the neighbouring village.

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[1] *Natural History of Ceylon*, p. 286.

Noisiness of amphibians

Being mainly lovers of the dusk, and also, in a small way, travellers, we find that most of the anura, the tailless amphibians (the frogs and their allies, that is), have developed loud voices. The croaking of our common grass frogs is nothing to the hideous din with which the tree frogs in Spain and Teneriffe greet the evening, or, rather, advertise their presence to their kind.

Reptiles not intelligent

Reptiles are singularly wanting in intelligence (I fear I may seem to have a "down" on them, but I am careful to do them justice). Let us see what power of learning from experience they show. Old crocodiles are more wary than young ones. Of the turtle's intelligence take this account from Sir J. E. Tennent:[1] "As if conscious that if she went and returned by one and the same line across the sandy beach, her hiding-place would be discovered at its furthest extremity, she resorts to the expedient of curving her course, so as to regain the sea by a different track, and after depositing the eggs, burying them about eighteen inches deep, she carefully smooths over the surface to render the precise spot indiscernible."

Very interesting, though it may be only a blind instinct on a par with the spinning of a cocoon by a silkworm. But whether we call it intelligence or instinct, the turtle certainly conceals her nest with more care than a certain wild duck that I remember. This wild duck had made a beaten track that led straight across the soft mud from the water to her nest, and this naturally led to its discovery. And yet the wild duck ranks generally, and with good reason, as an intelligent bird. As to snakes, they at any rate show some power of learning. The grass snake does not emit his offensive smell when his master appears, but keeps it for his enemies, real or supposed. Lizards grow familiar with those who feed and pet them. But one has only to look at a reptile's head to know that his mind is not of a high order: the forehead is low and the cerebral hemispheres very little developed. Connected with this subject is the absence of play among reptiles. Play develops intelligence. I am not speaking of the organised games which at school take the place of play properly so-called, but of play that calls forth the inventiveness of childhood. It is among puppies, kittens, young elephants, for instance, that we find the playful spirit, and it is among them that we find most intelligence. Birds disport themselves in the air and put forth all their powers of flight for mere delight in their own vitality and skill. In the same spirit many birds will sing in winter, when their singing cannot possibly be of any use to them. But unlike the puppy or the kitten, the bird seems to have no play into which fun enters, and his intelligence is (I regret to say it) inferior. A reptile has not the buoyant vitality of the bird, uses his strength in a mere utilitarian spirit, has no delight in motion and exercise, still less does he know the fun of playing. When a reptile is jolliest he merely basks in the sun.

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[1] *Naturalist in Ceylon*, p. 274.

They never play

Connected with the absence of play among reptiles is their indifference to the fate of their young. The young mammal is able to play because the stress of the struggle for existence does not fall on him directly, but on his parents. Youth is a careless time for him, during which he can, in play, rehearse the battle of life and sharpen his wits. But when the turtle has carefully deposited her eggs, she has done the whole duty of a turtle mother. The crocodile has advanced beyond this. "Some species" (I quote from Dr Gadow) "construct an elaborate kind of nest. The mother watches it, takes care of and fights for her offspring, numbers of which fall an easy prey to large storks, fishes, and the stronger members of their own kind."[1] I think this is the high-water mark of reptiles in respect of parental care for their young. But it must not be forgotten that the eggs of reptiles are large, much resembling

Little or no parental instinct

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[1] *Amphibians and Reptiles*, p. 447.

those of birds, except that all of them are of a uniform white. The egg contains a store of nourishment, and so far (but no further) the typical young reptile has a good start in life (fig. 44, p. 94).

Means of defence and attack

As a means of defence many reptiles have admirable protective coloration. The wonderful colours of the tree-snakes conceal them among the foliage. For attack, the poison-fang of the venomous kinds is an extremely formidable weapon, but it has its drawbacks. A rattlesnake, when trodden on by a stag, will, no doubt, bite the stag and kill him. But his own spine will probably be broken by the heavy tread of his victim. Deer are said to crush serpents by leaping on them with all their four feet. It is because his victory over a ponderous mammal may not save himself from destruction that the rattlesnake, by the hissing sound of his rattle, gives warning of his neighbourhood, on the same principle that a wasp, by means of his warning colours, advertises the deadliness of his sting. For it is no consolation to the wasp, suddenly grabbed and swallowed, that he can wound or kill the frog or bird that swallows him. The cobra, when angry, erects his splendid hood, the most beautiful thing I have ever seen in reptiles, presumably in order to scare his enemy.[1] He does not wish to have recourse to his poison, which may be more deadly than protective. Among lizards there is only one, the Heloderm, whose bite is poisonous. The non-poisonous snakes and lizards are much the nimbler. They make a dash for their holes when danger appears. Sluggish beyond all are the tortoises and their allies, survivals of a period long past, the period of heavy armour, which proved ineffective in comparison with activity and weapons of attack. A tortoise's house is his castle. But, unfortunately, he cannot leave it when he wants. The animals that have carried off the chief prizes of life are those which do not take the shocks of fortune passively, but which have speed of foot or wing to pursue their prey or to run from danger, or to migrate to more hospitable regions, and teeth, hoofs, claws, or spurs for fighting.

I have laid stress on the shortcomings of reptiles as compared

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[1] Sir J. E. Tennent, *Natural History of Ceylon*, p. 295.

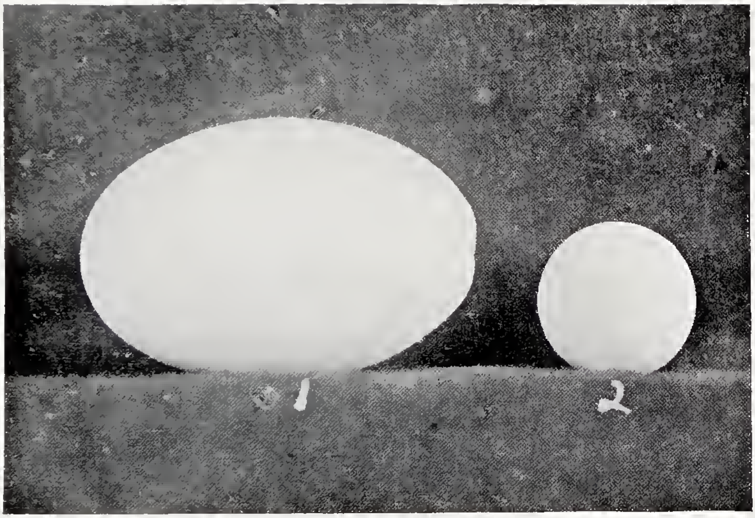

FIG. 44.—Egg of—(1) Crocodile; (2) Turtle. Rather over half real length.

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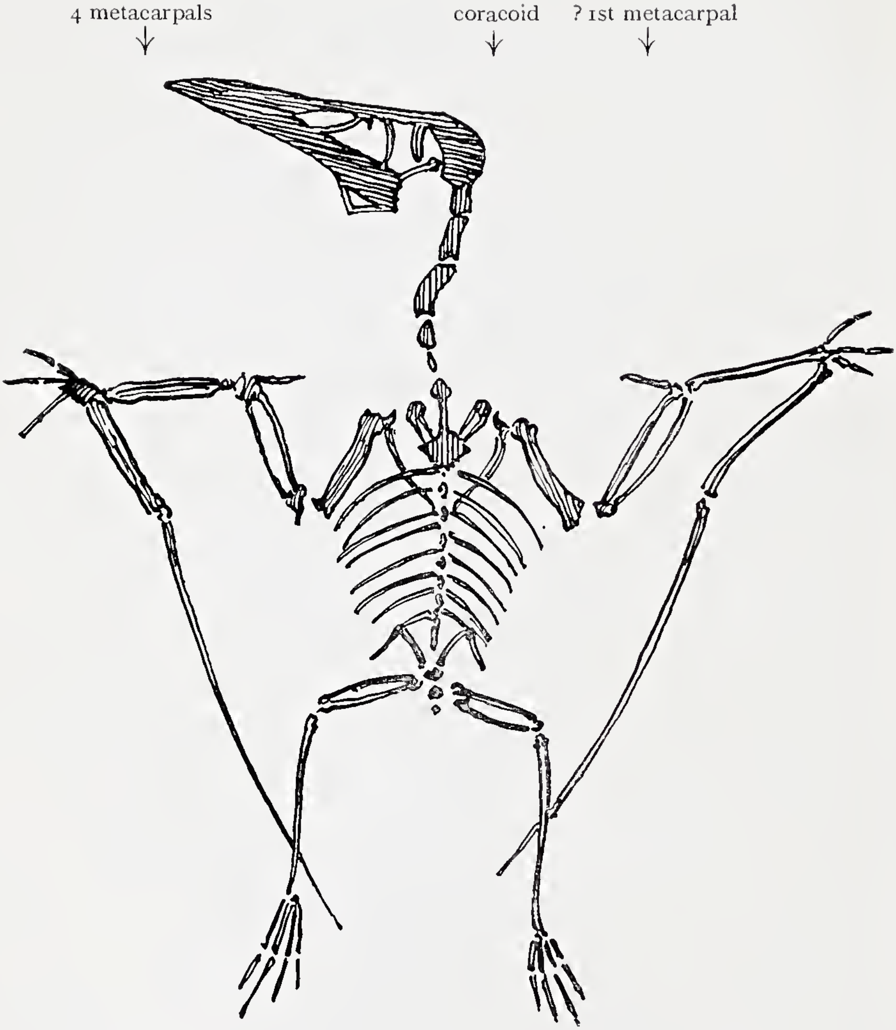

FIG. 45.—Pterodactylus spectabilis from lithographic stone in Bavaria, drawn from model in British Museum. About the size of a lark. Of the metacarpals, one is strong and bears the wing finger, three are slender; the small backward pointing bone is probably No. 1. The wing finger was divided into four phalanges. The breast bone was rounded outwards, the coracoid strong. Pterodactyles had no clavicle. The thigh bone is big, looking like two bones, the tibia long and stout. The fibula is thin, as in birds; it is not seen in this drawing.

Facing p. 95

with warm-blooded animals—their sluggishness, the quickness with which they tire, their want of intelligence—because those who make a study of reptiles, or keep them as pets, are apt to dwell overmuch on their strong points. They adopt a very low standard in judging of them, and so, no doubt, the reptile may appear a very fine creature. If you expect absolutely nothing in the way of intelligence, a chimpanzee may appear a genius. The fact is that the noblest of reptiles, the Ornithosaurs or Pterodactyles, are extinct. But through the labours of men of science, and notably of Professor H. G. Seeley,[1] we not only know their build and appearance, but feel pretty confident as to the grade in the animal series to which they belonged.

Noblest reptiles extinct

Pterodactyles

The Pterodactyles, or Ornithosaurs, were flying reptiles that made their appearance in the secondary period, when reptiles were predominant upon the earth, and disappeared before the end of it. They probably represent the highest point attained by what we call reptiles, being possessed, there is reason to believe, of more energy, vitality, and intelligence than any reptiles now found upon the earth. It is wonderful, on first thoughts, that the noblest of the whole class should have become extinct, while others, far behind them in everything, survive in these latter days of the world's history. But these survivors hide themselves away in holes and corners. The Pterodactyles played a bolder game, essayed the realms of air, and for a time held sway there, till the birds—younger aspirants than they, but their superiors—appeared in the arena, and, metaphorically, threw down the gauntlet. Then the Pterodactyles, the aristocracy of reptiles, were driven from the face of the earth. They could not, like the plebeian orders their relatives, lead a skulking life in the out-of-way corners conceded to them by birds and mammals.

The Pterodactyles, as the illustrations show, had long wings, very different in build from a bird's (fig. 45, p. 95). The wings

Wings

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[1] See his excellent book, *Dragons of the Air*.

consisted of a great expanse of membrane, of which the front margin was supported by the fore limb and one finger of enormous length (hence the name Pterodactyle or wing-finger), the hind margin attaching to the hind limb. It was, therefore, in general build, much more like the wing of a bat than that of a bird. And yet its scaffolding is very different. Only two fingers with their metacarpals go to the making of the bird's wings. The remaining one is of no account. Four fingers and their metacarpals support the bat's wing. Even the short metacarpal that carries the thumb contributes something (fig. 46, p. 96). But what concerns us more is the points of likeness and unlikeness between the Pterodactyle and its relative the bird. In the Pterodactyle only one finger forms part of the wing's architecture. And this one is either the fourth or fifth according as we regard the small backward-pointing bone (see figure) as the first digit, the thumb, or as a bone representing a tendon. The next three digits (Nos. 2, 3, 4 or 1, 2, 3), each carried by a very slender metacarpal, do nothing for the wing, but are armed with claws. Then comes the finger of monstrous length carried by a strong metacarpal (No. 4 or No. 5; if No. 4, then No. 5 is lost altogether). Now the bird, as I have said, has only three fingers on its hand, generally taken to be the first three digits or what we call the thumb, the first and second fingers. The thumb with its feathers has the name of the bastard wing and is independent of the wing proper, so that two fingers only form part of the framework of the wing, and neither of those is the one corresponding to the wing finger of the Pterodactyle. As far as the framework of its wing goes, we must conclude, then, that the Pterodactyle is neither a bat nor a bird.

No scales or feathers

The membrane is bare, carrying neither scales nor feathers. In the Solenhofen Slate, called the Lithographic Slate, because of the accuracy with which small details are engraved upon it, no trace of them is found. And this Solenhofen Slate has supplied many specimens of these reptiles. If there had been feathers, they would surely have been preserved, since the feathers of Archæopteryx, oldest of fossil birds, are seen, with much of the detail of their webs, in this same slate. In other ways the Pterodactyles are like the birds that have supplanted them.

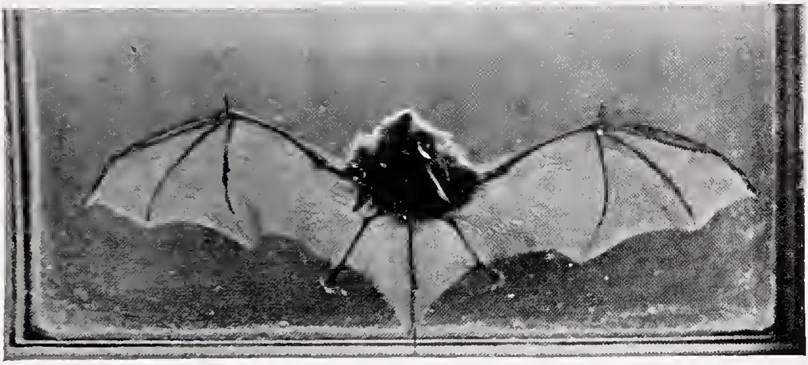

FIG. 46.—Bat. All five metacarpals and four fingers help to make the framework of the wing. The short thumb bears a claw.

Facing p. 96

Hollow bones

Their limb bones are hollow—not by any means a barren fact, but one from which Professor Seeley is justified in inferring that, if they were like birds in this, they were, like them, hot-blooded. Into the hollow bones of birds extends the bronchial membrane, sometimes reaching to the fingers. Air from the lungs fills the cavities, and though it cannot be expelled from them at will, yet their existence in Pterodactyles proves that they breathed as as only animals of the highest grade breathe. It was no sluggish, irregular, reptilian performance, but the breathing that means vitality and energy. It is such breathing that keeps up the temperature, makes the animal a furnace in which the fire burns keenly, and drives the whole machine at high pressure. The digestive apparatus has to keep pace with the lungs and dispose of large and constantly recurring meals. Adapting a Spanish proverb, we may say: "Show me thy bones and I will tell thee thy character." But if we are over bold in the inferences we draw from the sole fact that the limb bones of Pterodactyles were hollow, there are other facts that tell in the same direction. The skulls that have been found make it probable that the Pterodactyle's brain was like a bird's. "It happens that moulds of the brain of Pterodactyles, more or less complete, are met with of all geological ages—Liassic, Oolite, Cretaceous. They commonly have bones so thin as to show the form of the upper surface of the mould of the brain, or the bones have scaled off the mould, or remain in the counterpart slab of stone so as to lay bare the slope of the brain mass (fig. 41, p. 84). And thus the fossil remains of Pterodactyles show us that their brain was no mere succession of paired lobes like a reptile's, but, at any rate in some species, the optic lobes were forced out to the side as in the bird's brain."[1]

The skull

Looking at their hollow bones and the shape of their brains, Professor Seeley puts Pterodactyles above the rank of reptiles. But suppose, for the sake of argument, that neither the hollow bones nor the make of the brain justify us in drawing any grand conclusion with regard to them. Yet there is the great expanse of wing. In some of the Pterodactyles, from tip to tip is a span

Argument from the make of the wing

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[1] *Dragons of the Air*, p. 54.

of eighteen feet. There are other representatives of the order no larger than a sparrow. But big or small, no doubt they made use of their wings. They were clumsy on their legs. The wing membrane attached to the hind limb along the greater part of its length must have hampered their leg action. They were specialised for flight. And if they could only float with these large wing expanses and were at the same time the clumsiest of walkers, they must have been as helpless as penguins would be if they were no better at swimming than walking. They must, therefore, have flown, not merely floated. Nor can their flight have been a mere reptilian performance, a series of little starts interspersed with short rests. It is only because a bird is a good jumper that it is so easy for him to rise on the wing—for a small bird that is. For a big bird it is the beginning that is the difficulty. Now, only look at the restoration of a Pterodactyle and the verdict must be that the getting under way must have rather taxed his powers. Unable to rise from level ground he might fall a victim to a clumsy Dinosaur (fig. 36, p. 79), for certainly jumping was not his forte. This being so, his progress cannot have been made up of very short flights, a series of beginnings. Once well started, there is every reason to believe he could give a powerful wing stroke. The breastbone rises into a kind of crown, suggesting the keel of a bird's breastbone, and giving room for the attachment of strong flight muscles. There is ground, then, for believing that the Pterodactyle was strong on the wing and could maintain himself in the air for some time. Existing reptiles, however quick and agile, are constantly stopping to rest. The Pterodactyle must have been capable of more sustained activity, since to alight and start again was no easy task for him. His anatomy, too (notably his breastbone, as I have said, and the wing itself), supplies evidence of powerful flight. And powerful flight is proof of high vitality. Thus to supplement the evidence that Professor Seeley adduces—the build of the brain and the hollow bones—we can, with confidence, draw inferences from the Pterodactyle's machinery of flight coupled with his clumsiness on foot. Flight, sustained flight, was possible to him—it was practically his first and last resource—and this implies great physical vigour, efficient breathing apparatus, maintenance of temperature, and so forth.

Why have Pterodactyles become extinct?

Why, then, did Pterodactyles become extinct?

Warm-blooded, with a large expanse of wing moved by powerful muscles, if we judge by the bones from which they sprang, with no mean brain capacity, the Pterodactyles have nevertheless disappeared. Their light paled before the sun of a more brilliant race, the birds. The rivals were equally reptiles, though reptiles ennobled by the acquisition of powers and characters that we do not usually associate with the name. We must dub both or neither reptiles, that is, if we are right in believing that Pterodactyles were the high-grade animals that from their fossil remains we have inferred that they were. But if they are to be put in the same grade as birds, what were the points of inferiority that caused them to lose the race? One I have already mentioned. They were not good on their feet. I take it they must have been capable of a biped gait, or else their spread of canvas would have encumbered them hopelessly. But even with a biped gait, the membrane reaching nearly to their feet must have hampered them in walking as a lady tennis player is hampered by her skirts. Professor Seeley feels this, and tries to show that in some Pterodactyles (*e.g.* in Rhamphorhyncus), the wing membrane was not attached to the leg.[1] But in other species it undoubtedly extended far down the leg, and I very much doubt whether without this attachment it would have had framework sufficient, since it would have had to depend for the support of the part near the extremity, where the strain in flight would be greatest, on the long wing-finger alone. Compare the other membranous wing with which we are familiar, the bat's. Four fingers, five metacarpals, and the leg go to form its framework, while the tail supports the backward extension.[2] We must not put too great a strain on this wing-finger whose wonderful elongation accounts for more than half the stretch of the whole wing. In Rhamphorhyncus it is more than twice the length of the rest of the wing. But this genus seems to have carried this essentially Pterodactylian feature to its utmost extreme.

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[1] *Dragons of the Air*, p. 165.

[2] Fig. 46, p. 96.

Apart from the question of adequate framework, we must consider the necessity of supporting the hinder part of the body. The bird has its tail which it is able to spread to a great width. Pterodactyles have, some of them, long tails, some of them very short ones. But the tails of none of them had much supporting power. In the case of most the tail has absolutely no expanse of membrane. True, that of Rhamphorhyncus spreads out like a leaf at the end (fig. 36[1]). But it must have been picturesque rather than serviceable, so small is its expanse if we compare it with a bird's tail. These considerations drive us to the belief that not only some but all Pterodactyles had the wing membrane attached to the leg, extending low down to near the ankle. No doubt it incommoded them in walking, but without this attachment I do not think they could have flown, and if they were unable to fly they would have been monstrosities, winged creatures incapable of flight, and at the same time very poor walkers.

To pass to another point. The Pterodactyles were almost undoubtedly warm-blooded. Temperature depends on the rapid oxidation of the blood, and that depends on the efficiency of the breathing apparatus. There is no reason to suppose that the breathing apparatus was anything but efficient. But the maintenance of temperature in a cold climate by rapid unceasing oxidation is a very exhausting process. To sit long in a cold room with scanty clothing reduces the vitality of a human being. If in health, he will maintain his temperature, but at the cost of the burning of much tissue—a decidedly weakening business. In cold regions man has to wear clothes. Without this protection the effort of keeping his temperature up to 98° and a fraction would debilitate him, and before long he would succumb. A bird has its feathers to shield it. But a Pterodactyle had no feathers nor even scales, nor yet the hair of mammals. In a cold climate, or in a time of exceptional cold, Pterodactyles would have been at a disadvantage as compared with birds. True, the fossil remains show that they flourished in Britain. But there is evidence that in the secondary period the British climate was warmer than it is now. It may be argued that birds migrate because they cannot stand the cold of winter. But gulls will disport themselves in the sea when its temperature is down to the freezing-point, or near it, nor are other birds much affected directly by cold. It tells on them by cutting off their food supply.

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[1] P. 79.

In an anatomical point, small but important, the bird had the advantage of the Pterodactyle. The latter had no clavicle (wishbone, merrythought), and the work of the clavicle is to help to make a firm pivot for the wing. The loss of this by the Pterodactyle I am unable to explain. As to teeth, we need not say much. Some species of Pterodactyles lost them, while some species of birds, now extinct, retained them.

Points in which a bird is superior

I have now mentioned the chief points in which the bird outdistanced his rival.

(1) He was far better on his legs, at home on the land as in the air, and consequently far better at "taking off" for flight.

(2) Having a warm coat it was easier for him to maintain the high temperature that rapid oxidation gave him.

(3) He had an efficient tail, very useful in supporting his hinder quarters during flight and in balancing.

(4) He had a fairly strong and well-set clavicle to aid in forming a pivot for the wing.

In these points the bird had the advantage, and so became the undisputed lord of the air.

Note on the Reptiles of the Secondary (Mesozoic) Period.—The reptiles of this period have been much studied, so that their anatomy is well known and their habits may be inferred. Huxley made a special study of the Dinosaurs, in which the ilium, extending forward as well as backward from the thigh joint, as in birds, suggests a biped gait. Professor Marsh has published a monograph on the Dinosaurs of N. America, and the best known restoration of a Pterodactyle is due to him. But, perhaps, Professor Seeley has done more than any other investigator for our knowledge of Pterodactyles. Dr Fraas is the author of a valuable monograph on the Ichthyosaurs. But the collections at the British Museum are more instructive than any monograph. The restoration of Mesozoic reptiles in Mr H. N. Hutchinson's well-known book, *Extinct Monsters*, are excellent; Dr Gadow (*Amphibia and Reptiles*) is as good on extinct as on living reptiles.

Chapter V

FROM A REPTILE TO A BIRD

Specialisation for flight and all that it involves

We can hardly doubt that birds have sprung from reptiles. Later on I shall speak of Archæopteryx, a fossil bird that very much suggests a lizard, though it is an undoubted bird.

The ancestors of birds, then, were a kind of lizard. The typical lizard, as we know him, barely lifts his body above the ground when he runs and makes his short, sudden darts. Even Chlamydosaurus is cold-blooded and has little staying power. The bird, the typical bird, rises in the air, and we measure the distances he covers, not by yards, but by miles and hundreds of miles. He has made flight his speciality, and nearly all the peculiarities of his anatomy are traceable, directly or indirectly, to this fact. His fore limbs, then, have become wings, and the covering scales have been elaborated into feathers. But wings are useless without very strong muscles to move them, and very strong muscles require a very large expanse of bone for their attachment (fig. 49, p. 104). We find, then, as we shall expect, that there are huge muscles (huge relatively to the size of the bird) to work the wings, that the breastbone has developed a great projecting keel, and that the connected bones are much strengthened. It is only birds, such as the ostrich, which do not fly that have no keel (fig. 50, p. 105). It is a necessity, if room is to be found for the attachment of the great and ponderous muscles of flight. There must be a reduction of weight elsewhere, and many of the bones, notably in the larger birds, have become hollow. Further transformation follows. The fore limbs having been turned into wings, useless in walking, the hind limbs must be greatly strengthened in order that our bird may be capable of a biped gait. But a biped must have hands or something in place of them. The wings are too specialised to be used as anything but wings. The neck, then, had to be lengthened, the skull to be lightened, and a horny beak (in place of heavy jaws armed with teeth) to be grown to do the work of a hand. But if the bird is to be constantly bending down to pick up this and that, his back must be strengthened and stiffened, or it will ache intolerably. Strong and stiff it is—largely owing to an extension of the pelvis. Then, all this machinery requires an engine to work it. The heart and the lungs must be enormously above the old reptilian standard, the appetite and digestive powers must be great. All this leads to a high temperature under the control of special nerves or nerve fibres. It involves, too, some contrivance for preventing a too rapid loss of animal heat. Hence a general coating of feathers. Then there arises a further difficulty to be met by further adaptations. If appetites are great and there are constantly recurring meals, the supply of food in particular districts or particular regions will in certain seasons run short. This will lead to long flights being taken and eventually to migrations on a large scale. But if the birds of a species become widely scattered, they must have some means of finding each other again and of recognising a kinsman when he is found. Hence the wonderful development of voice among birds, especially those that are small and inconspicuous, and so most likely to lose each other. Even the nightingale's song began, I believe, as a mere call. Reptiles are sedentary and silent. But many birds have, in addition to their call notes or their songs, conspicuous plumage. A characteristic dress also is wanted for recognition. And as in many birds the call note has been glorified into a splendid song to attract and charm the hen, so the distinctive plumage that was useful merely for recognition has by a like extension developed into a thing of brilliance and beauty. Lastly, keen ears and keen eyes, indispensable for other purposes, are indispensable also for the recognition of call notes and of distinctive plumage. And so all the crude material ready to hand in the lizard-like reptile has been worked up into something rich and strange.

Many things that on first thoughts seem to have no relation to one another we must connect together—the metamorphosing of the fore limb into a wing, the enormous breast muscles, the keel of the breastbone, the strength of the legs and the biped gait, the length of neck, the lightness of the skull, the horny beak, the stiffening of the back, the great development of the pelvis, the levelling up in respect of heart, lungs, and digestive apparatus; the high temperature, the general coating of feathers, call notes, song, brilliant plumage, keenness of ear, keenness of eye. Indeed, a bird is a mass of mutually adapted perfections.

The fore limb

We must now study these matters more in detail, and first the metamorphosing of the fore limb. A wing must be stiff when it strikes downward. A lizard's fore limb is weak, and cannot be straightened and stiffened. His five fingers bend and waggle (fig. 47, p. 102). Moreover, a broad expanse to bear the feathers is wanted. When the wing is extended it is held stiff by ligaments at the elbow. (Our elbow-joint allows much more freedom of movement even when the arm is held straight out.) Moreover, of the two rows of bones at the wrist-joint (the carpal ones), the more distant are fused with the hand bones (the metacarpals) beyond. So that, fusing the words as the bones fuse, we have a carpo-metacarpus. When the wing is fully extended it is rigid at the wrist. But bend the hand backward (away from the thumb) and the wrist-joint at once allows a downward bend. This takes place when the wing is being raised (fig. 53, p. 106). Of the normal five fingers the bird's hand has only three, and there are three metacarpals to support them (fig. 51, p. 105). All three metacarpals are fused at their base. No. 1 is small and unimportant; No. 2 is broad and strong; No. 3, after describing a curve, unites again with it at the further end. Of the three digits, No. 1 (generally considered to correspond to our thumb) is small and unimportant; No. 2 is broad and strong, and is attached almost rigidly to its metacarpal; No. 3 is insignificant. It results from all these changes that the fore limb can be held stiff, and that it offers a broad expanse for the support of the feathers.

The breastbone and connected bones

We can now go on to consider the changes in the breastbone or sternum and the connected bones. The strong muscles necessary for flight need a large surface of bone from which to spring. Hence the keel that projects from the breastbone in all birds that fly. They are known as the Carinatæ (or keeled birds) in contradis-

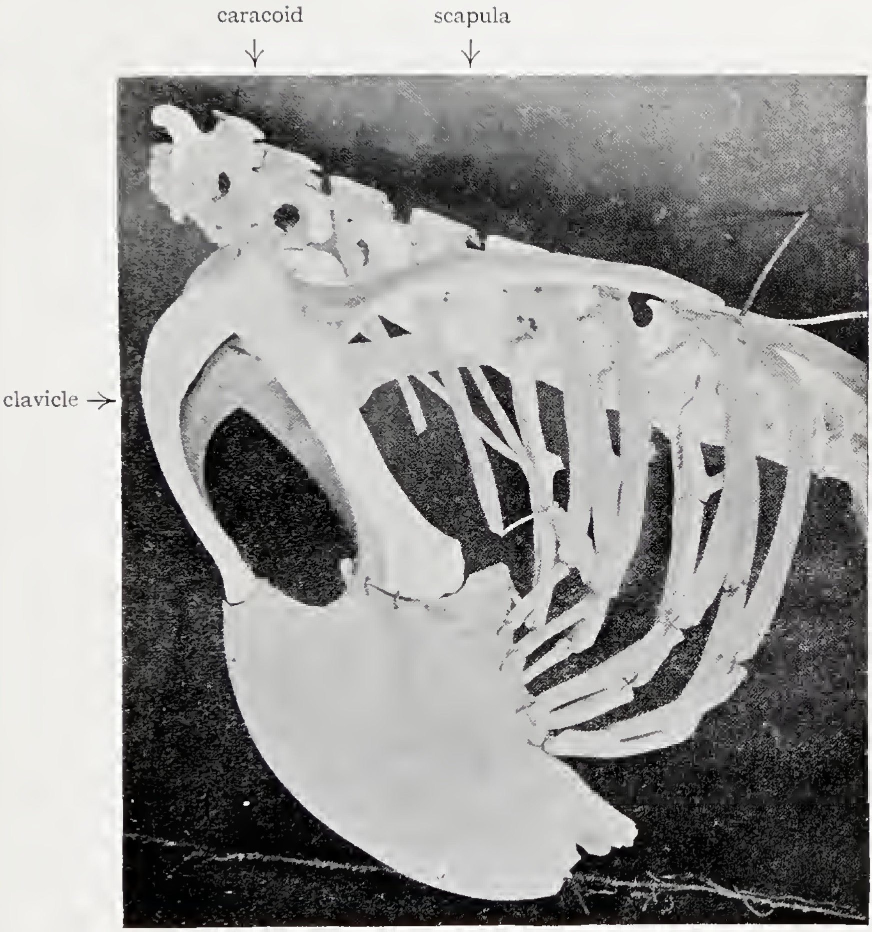

FIG. 49.—Sternum or breast bone (short, but deep) of Adjutant Bird. Coracoid stout and strong. Rather less than half real length.

Facing p. 104

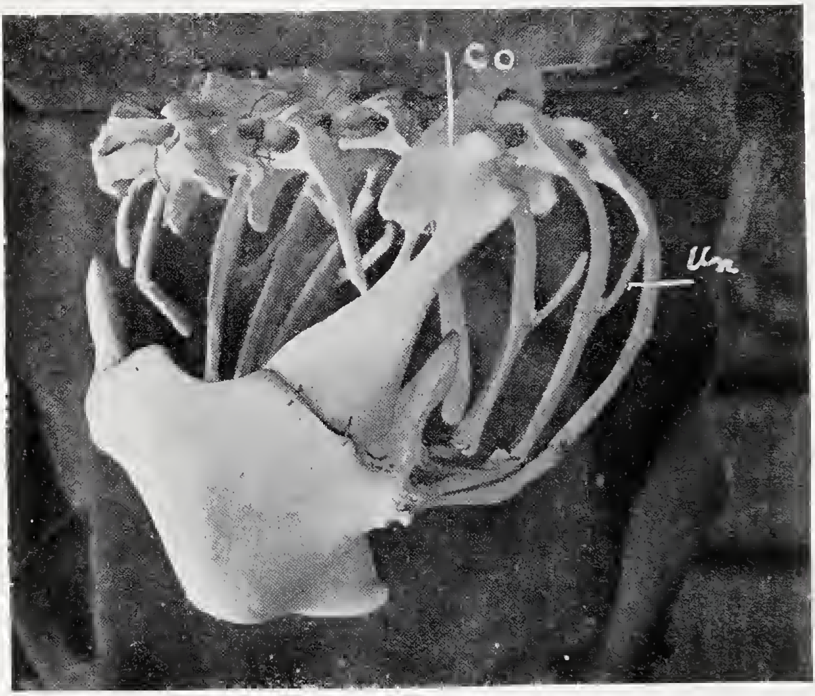

FIG. 50.—Sternum of Rhea (just over one-third actual length). Much more rounded outwards than that of the Ostrich. Co, coracoid (has a remnant of a pre-coracoid. *Cf.* the lizard, fig. 47, p. 102); Un, uncinate process.

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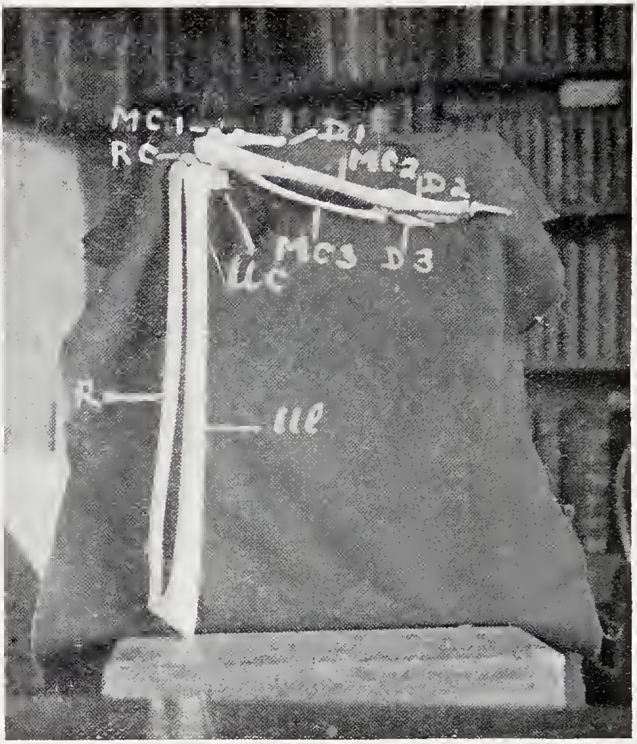

FIG. 51.—Skeleton of wing of Adjutant Bird—D1, D2, D3, digits 1, 2, 3; MC1, MC2, MC3, metacarpals 1, 2, 3; R, radius; RC, radial carpal; Uc, ulnar carpal; Ul, ulna (the small elevations from which the flight feathers spring do not show).

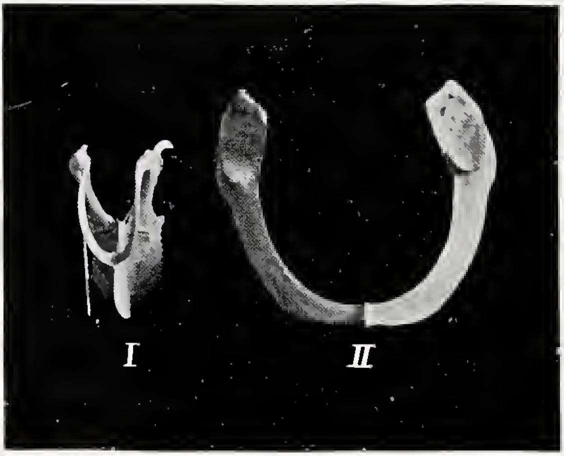

FIG. 52.—Clavicles of—I, Tern; II, Eagle. Half actual breadth.

Facing p. 105

tinction to the Ratitæ (ratis meaning a flat-bottomed keelless boat), such as the ostrich and rhea (fig. 50, p. 105, *cf.* fig. 47). A firm pivot must be formed for the wing, and this is made by a great strengthening of the coracoid bone, which projects as a strong strut from the forepart of the breastbone and meets the clavicle (wish-bone, merry-thought) at the shoulder joint, where they together form the pivot required (fig. 49, p. 104). As a rule, the stronger the bird on the wing, the more outward the slope of the coracoid. But mere size has much to do with it: the larger the wing the greater the pressure on the pivot. The clavicles also vary much in make and stoutness, not always obviously in accordance with the power of flight (fig. 52, p. 105). The great muscle that pulls the wing down, the depressor, springs from the keel and the side of the breastbone, and also from the clavicle. It ends in a tendon (a connecting rope, that is, with no power of contraction) that attaches to the humerus or upper-arm bone on its underside and near its front edge.[1] The pair of depressor muscles account for one-fifth, or very nearly that, of the weight of the whole bird, so all-important is flight. The elevator muscle, for reasons explained later on (see p. 144), is much smaller. It lies underneath the depressor muscle, in the angle between the keel and the flat of the sternum, and sends a tendon through a tunnel[2] formed by the meeting of three bones—clavicle, coracoid, and scapula (shoulder blade). Thus the tendon gets above the humerus and attaches to its upper surface, so that a pull upon it raises the wing and sets it with its front margin turned in the direction the bird is travelling.

The legs

The legs of a Dinosaur suggest, though but roughly, those of a bird: for biped gait the typical reptilian legs have undergone much alteration. In the bird, as in the horse and the stag, the ankle is high in air. Of the five bones of the foot[3] three are fused together; of one there is only a vestige, one is lost. Thus in the bird's skeleton there is one strong upright bone to represent the foot. The bird, like other good runners, goes on his toes. There are no separate ankle bones (tarsals). One of the two rows is fused with the leg bone above,[4] the other with

[1] Fig. 75, p. 144.

[2] The foramen triosseum.

[3] Metatarsals.

[4] The Tibia.

the foot bone below. And thus we have, for the benefit of those to whom long words are a help, a tibio-tarsus and a tarso-metatarsus, the ankle bones or tarsals having given up their separate existence. The other leg bone, the fibula, is a mere vestige.[1] This fusion of bones has, I think, helped to ensure the bird's safety when he sleeps perched on the branch of a tree. What if he were to fall during sleep? This is prevented by the automatic action of tendons which make the toes grip when the ankle-joint is bent, and during sleep it is kept bent by the bird's mere weight. The tendons originate above the ankle-joint and pass in a sheath behind it to the toes. The fusion of the ankle bones with the bones above and below has, I think, improved this automatic pulley. Certainly it is an excellent one.

The neck, backbone and head

The hard work thrown upon the hind legs necessitated the strengthening of the neighbouring parts of the skeleton. The pelvis in a bird is very characteristic.[2] It extends a long way on either side of the thigh-joint, forward as well as backward, arching over the backbone and rendering it absolutely rigid; in the lizard it extends in a backward direction only (figs. 47 and 48, pp. 102 and 103). The fore-part of the bird's backbone is also stiffened, there is no free play anywhere except at the waist, and this rigidity is a great help to the bird, carrying his body as he does, and having so often to bend forward to pick things from the ground. The neck is more supple even than a snake, turning with equal freedom from left to right and up and down, whereas for the snake the former movement is the only one easy. This is due to the way the bird's neck vertebræ articulate with one another (fig. 55, p. 106). Each is shaped like a saddle at its hinder end, and its neighbour is the rider in the saddle, having free movement forward and back and also up and down. The snake's ball-and-socket joint allows less freedom of up and down movement, as you see if you hold a snake by the tail. The bird's head is a most typical part of him. The skull is no thicker than paper and contains considerable air cavities. The loss of teeth, found only in some extinct species, still further reduced the weight of the skull. It was most

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[1] Attached to the Tibia.

[2] The pelvis consists of right and left halves, each formed of three bones, the Ilium (always joined to the backbone), Ischium, pubis.

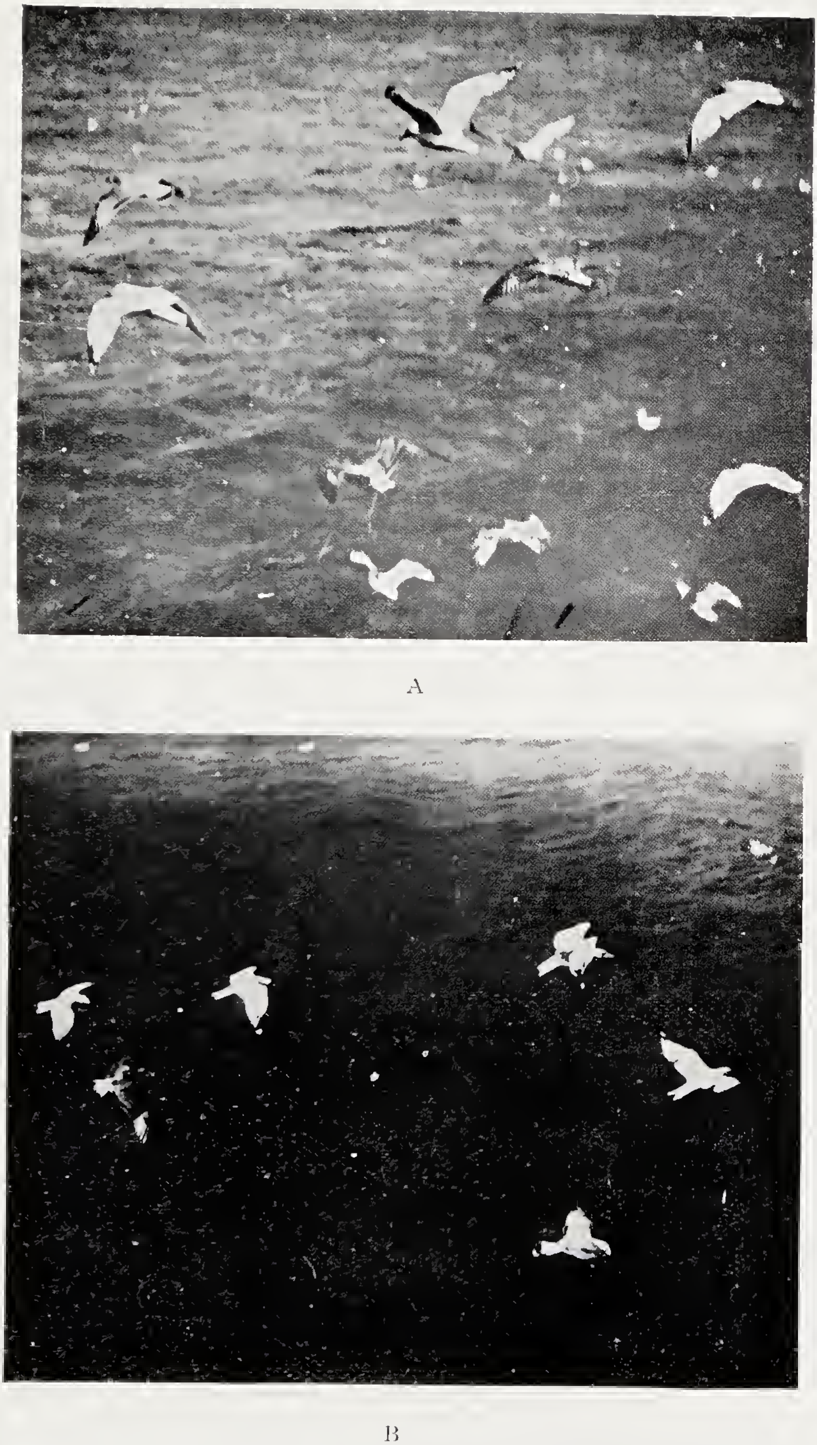

FIG. 53.—A, black-headed Gulls flying. The two on the left show the flexing of the wing at the wrist when it is being raised. Several have mottled immature plumage. B, black-headed Gulls. The one furthest to the right illustrates the moulting of the wing-feathers in pairs. (In September their heads are no longer black.)

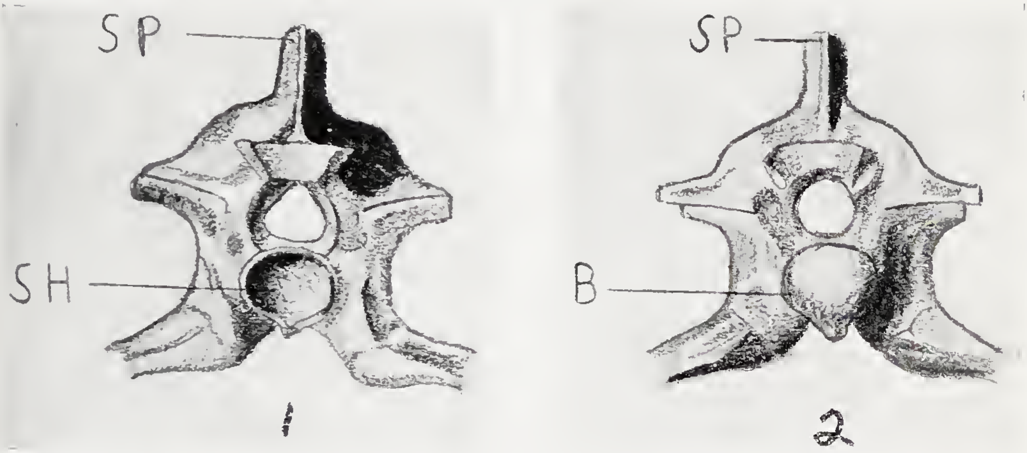

FIG. 54.—Vertebræ of Snake, to show ball and socket articulation—(1) anterior end; (2) posterior. SH (mistake for SK), socket; B, ball that fits into it; SP, dorsal spine.

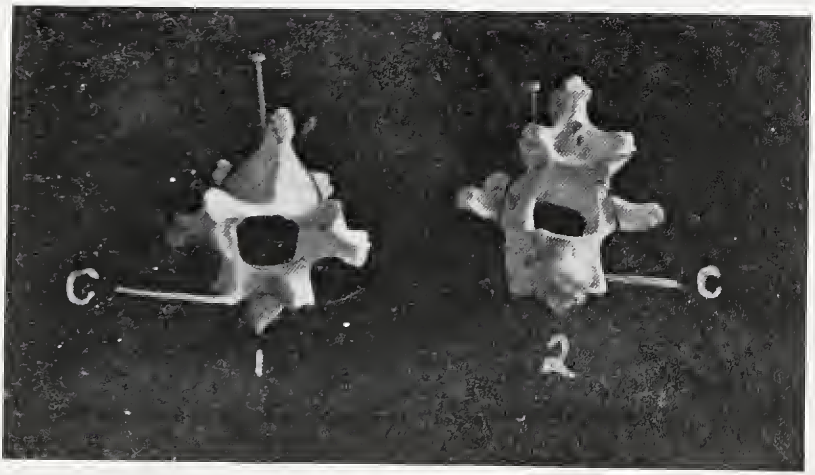

FIG. 55.—Cervical vertebræ of Eagle—(1) anterior end; (2) posterior. The centrum (c) of (1) is concave from left to right, and fits into the centrum of (2), which is concave from top to bottom, as a rider fits into the saddle.

Facing p. 107

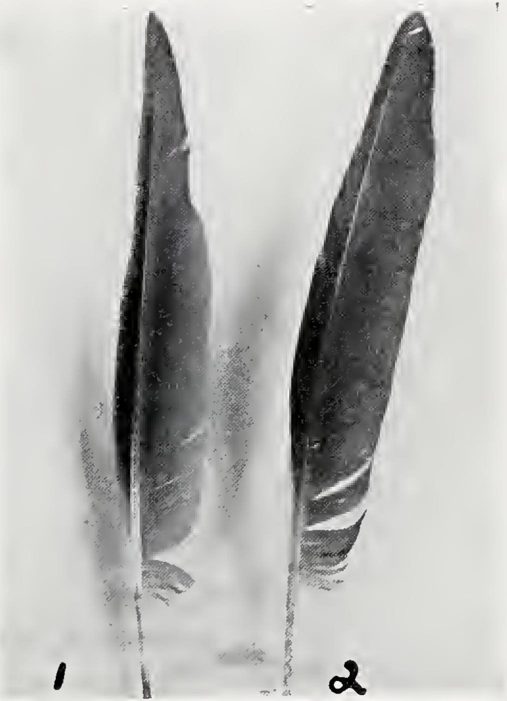

FIG. 56.—Primary wing-feathers of Heron, two-ninths of real length—(1) the first primary—the under side slightly concave, with groove down shaft; (2) upper side of feather, slightly convex. In both the outer web is much narrowed.

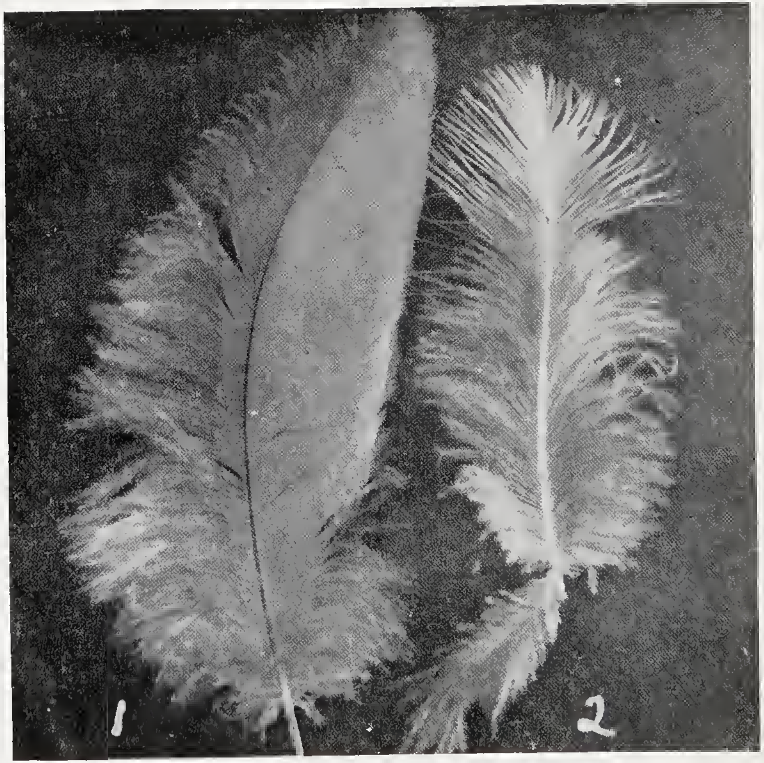

FIG. 57.—Feathers of Heron—(1) part of it downy, part firmly built; (2) having shaft and after-shaft.

important that the neck, having to act as an arm, should not have to carry over much weight. And a heavy skull would have made the question of balance more difficult during flight. The long tail of its lizard ancestors is in the bird reduced to the small pygostyle bone, a number of vertebræ welded together, from which spring muscles that work the rectrices, the great tail feathers so important in flight.

The feathers

The feathers now call for attention. Look at a feather and the scale of a lizard together, parts of the machinery of lives that are far as the poles apart. It is a long way from the gait of a lizard to flight, from little starts and sprints to migrant voyages across wide stretches of sea. And it is a long way, no less long, from the scale of a lizard to the wing-feather of an eagle. Yet there is no doubt that a feather and a scale are alike epidermic growths, and that moulting corresponds to the snake's shedding of his "skin," to the shedding of the horny covering of his scales. The feather springs from a little skin papilla, a little rounded elevation, the actual horny covering of the scale and the actual feather being formed from the epidermis that covers the papilla. First in the young bird comes the nestling feather with its threadlike branches, not facing in any particular direction, simply a quill many times divided. When the feather proper comes, the little nestling "down" is mounted on the top of it. In the young pigeon, and many other birds, it keeps its position there for some time, being really part of the same growth. We have nothing here similar to the succession of teeth, the milk-tooth followed by the permanent tooth. After the feather proper is formed, the pulp within the quill dries up till moulting has taken place, and the blood moves up into the papilla to form a new growth. But the nestling down and the feather that follows it grow from one and the same pulp.

Though the feather is a scale, it is a highly elaborated scale. First comes the quill, with the dried remains of the pulp, the soul of the feather, as the Germans call it, still visible. Above is the rachis or shaft, grooved down its front face (fig. 56, p. 107). From it springs the barbs, sloping towards the tip of the feather; from the barbs branch out the barbules or radii. From the barbules, on that side of the barb which is nearer to the tip of the feather, spring the barbicels (diminutive of a diminutive), that fasten barbule to barbule, and thus gives the feather its strength and elasticity, besides making it impervious to air (fig. 58, p. 108). The barbicels have another name, hamuli or hooklets, from their shape. On the side of the barb which is nearer to the base of the feather the barbules bear no barbicels, but their endings resemble hairs. Their hairlike endings are neatly folded together so as to form a kind of hem (fig. 58, A and C). The opposite set of barbules lie over these smooth-ending ones, and among them they insert their hooklets. The hooklets slide along the barbules when a strain comes on them, and to this very largely must be due the elasticity of the feather. The "hem" just mentioned prevents them from sliding too far. Moreover, the barbicelled barbules are waved (fig. 58, A and C), and this, no doubt, adds to the elasticity. The upper side of a feather, if you examine it under the microscope, is untidy: the barbicelled barbules leave their extremities (the extensions beyond the hooklets) lying raggedly on the surface. The under surface of the feather, the side against which the air strikes during flight, is smooth. The number of barbules is enormous, according to Dr Gadow, over a million in one large flight-feather. It is to be noticed that the barbules with hairlike endings make a smaller angle with the barb than the barbicelled ones. Here is another very interesting point; on the margin of the barbules, opposite to that which is armed with barbicels, are rough nobs. These are, I believe, the vestiges of barbicels, which, being useless, are in process of disappearing. The feather, in fact, is thrice pinnate. The main shaft branches into barbs, the barbs branch into barbules, the barbules branch, or did branch formerly, into barbicels. But the barbules on the side nearer to the base of the feather have altogether lost their barbicels, while the other set have only one member of each pair of hooklets properly developed, the other member being represented by a mere vestige, so that they are lopsided, with rough nobs to match the barbicels.

What I have been describing is one of the strong flight-feathers in the wing or tail (remiges or rowers in the wing, in the

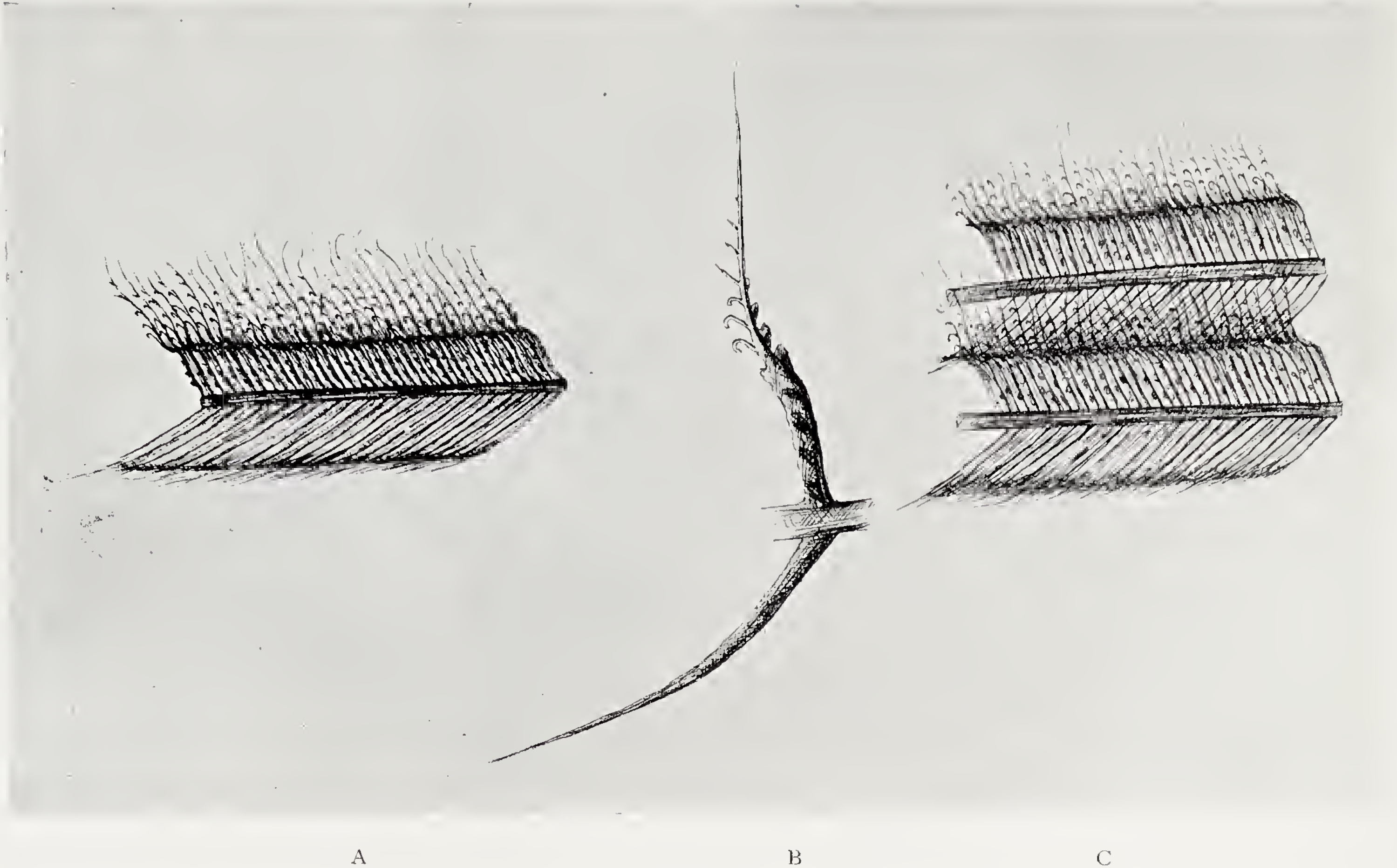

FIG. 58.—A and C × 90 diameters, B × 250. A, a barb; C, a pair of barbs showing interlocking; B, a pair of barbules showing the barbicels on the one nearer to the tip of the feather.

Facing p. 108

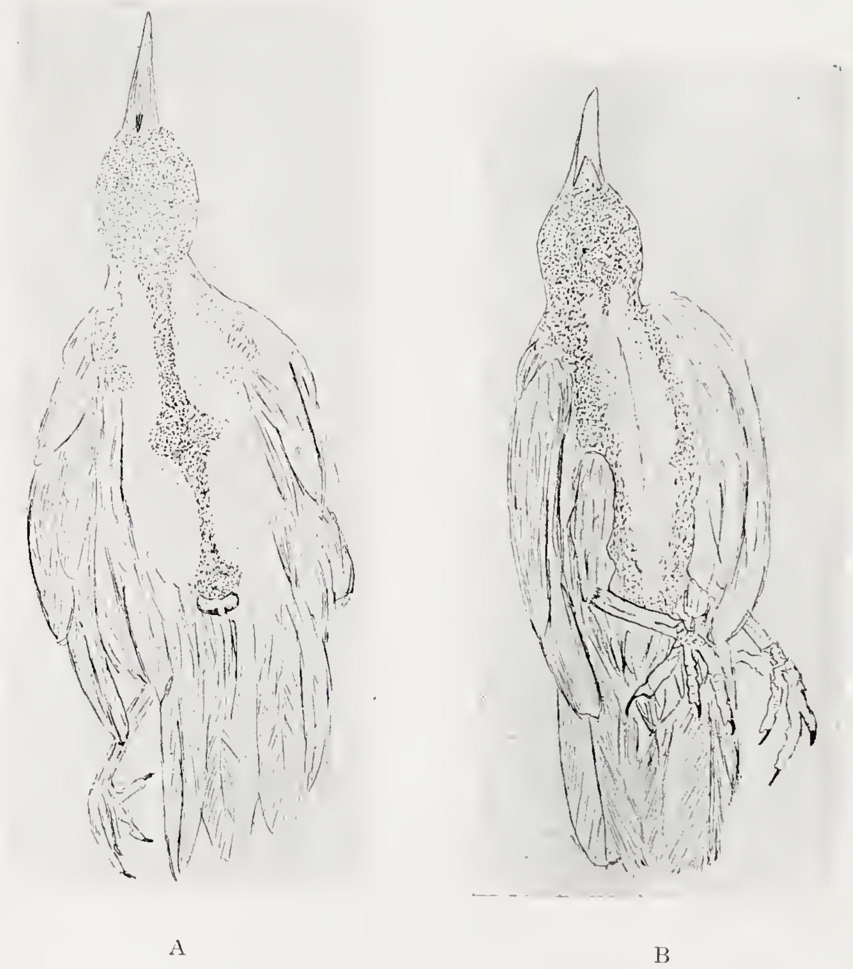

FIG. 59.—Starling—A, back; B, breast. Partly plucked to show the apteria or bare tracts. The feathers grow only where the surface is dotted. The oil-gland is conspicuous.

Facing p. 109

tail rectrices or steerers). The contour feathers, that shape the bird, are not in every way the same (fig. 57, p. 107). In some, throughout their extent, in parts of others, there are no barbicels, and they are in consequence much more downy. Such feathers often have a short aftershaft (fig. 57, 2). In the Cassowary the aftershaft almost, or quite, equals the main shaft in length. Had all feathers once this aftershaft? In some families of birds it is well developed, in others it is barely traceable, but in no bird except the Emu is it found in the nestling-down feathers, which suggests that primitive birds had no aftershaft. Among the large feathers are little down feathers or "downs." There are also filo-plumes, thread-like feathers growing close to the larger feathers, and in the heron and some parrots there are powder-down feathers on the breast, so called because they shed a fine powder.

So much for the structure of feathers. They clothe the bird and shield him from the cold, though they grow only over certain tracts, leaving apteria (fig. 59, p. 109), or bare regions, that are possibly of service in keeping down the temperature of the bird during hard exercise (for the bird can raise his feathers to allow a current of air to play over his unclothed parts), and are certainly of use to the ornithologist in dividing birds into their different families. Only in the penguins do the feathers completely cover the body.

The spreading of the wing and tail

Some further account now of the great wing feathers in connection with flight. It is most important that they should be firmly planted. Though they arise in the epidermis, they grow inwards and attach their bases to the bone—I am speaking of the secondary feathers which make their mark in the ulna (fig. 51, p. 105).[1] But firm planting alone is not enough; a mast would soon go overboard if there were no stays, and so the great feathers are firmly held by elastic ligaments. The most important of these, easily seen if the small feathers are removed, arises from the armpit and extends to the finger tips. Through it pass both the secondary and primary flight-feathers (fig. 60, p. 110). It is, in fact, the continuation of a tendon, and connects with a muscle arising from the ribs. The tail, also, has

[1] They do not show in the reproduction of the photograph.

its elastic ligament, which holds the feathers fast in the same way and helps the muscles to spread them like a fan.

Now the feathers have no activity of their own. They must be extended and put in position for flight by muscles. Take a dead bird, one freshly killed, and it is easy to make out how the machinery works. Extend the arm by straightening it at the elbow joint, which is quite near the body, and the hand is also of necessity extended and brought nearly into line. When the hand is extended, the great feathers spread like a fan, marshalled in their places by the elastic ligament through which they pass. At the same time they are slightly rotated, slightly twisted round, so that the near side of the vane of each is closely pressed against the off side of the one that overlaps it, thus making the wing impervious to air. In fig. 61, p. 111, may be seen a muscle marked F, divided into two, and passing from the elbow to the wrist. When the wing is extended this contracts, and one part of it pulls the small tendons which pass under the quills and attach to their further side. The pull of the tendon causes the feather to turn a little on its base. This is helped by the rush of air caused by the rapid descent of the wing. The outer web is comparatively quite narrow (fig. 56, p. 107). Hence the wind presses much more upon the inner web and tends to rotate the feather, thus supplementing the work of muscles and tendons. The elasticity of the feathers comes into play. As the wing descends, their downward curve is lessened by the pressure of the wind. When the stroke is over, there is a rebound and they recover. This elasticity saves them from breaking.

Moulting

All this splendid machinery of feathers has been developed out of reptilian scales, metamorphosed almost beyond recognition. Another change has accompanied the elaboration. The lizard or the snake "sheds his skin" all at once, the snake's comes from him in one piece. But this would not do for a bird who must be able to take to his wings whenever danger threatens. So the big flight feathers, as I have already remarked, are shed gradually in pairs, corresponding feathers on the right and on the left dropping out and leaving gaps, as may be seen in one of the photographs of gulls (fig. 53, p. 106). Geese

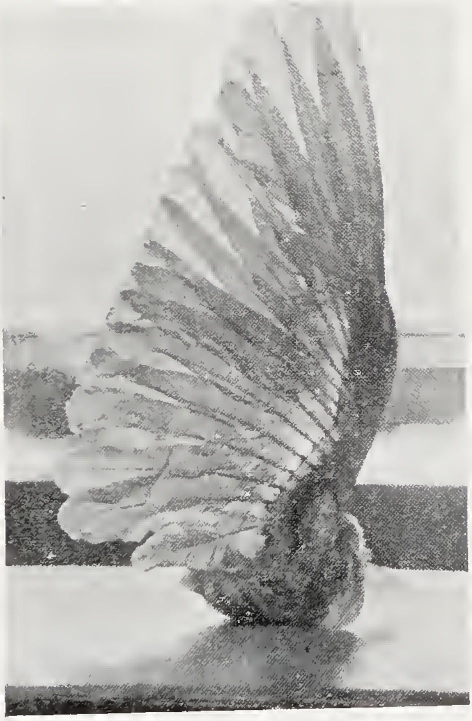

Fig. 60.—Wing of Blackbird, with some small feathers removed. The elastic ligament that spreads the wing-feathers is seen near the bases of the quills.

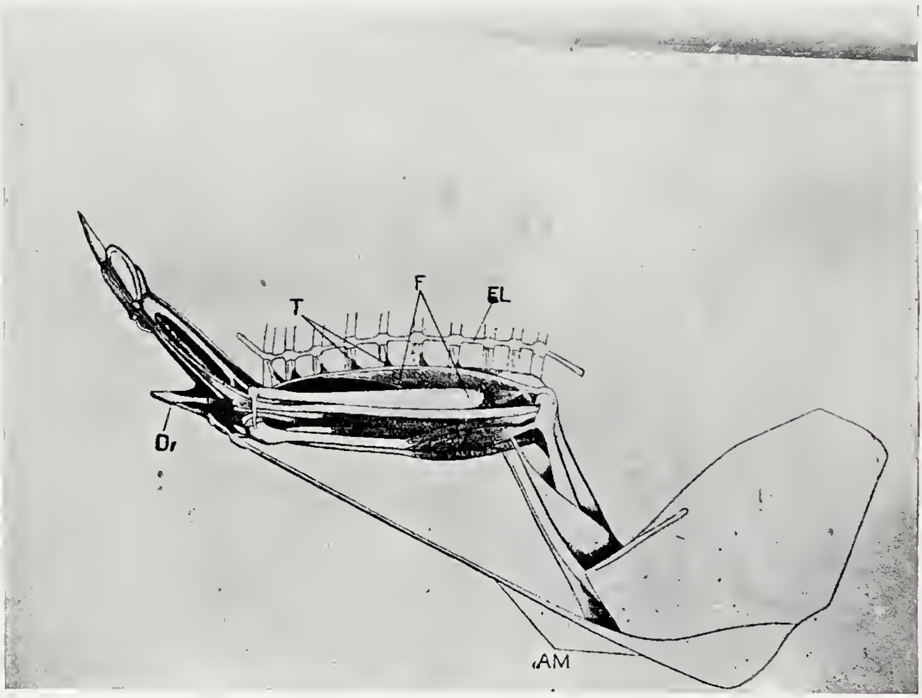

FIG. 61.—Wing viewed from below (after Alix)—AM, muscle and tendon supporting anterior membrane; D1, digit 1; El, elastic ligament; F, flex or carpi ulnaris, dividing into two; T, tendons that rotate quills.

Facing p. 111

and ducks, however, have not this admirable system of gradual moulting. While they are shedding their feathers and growing new ones they keep out of danger as far as possible. But in the arctic island of Kolguev[1] the moulting geese on the lakes are driven into nets by the thousand. Unable to fly, they have to submit to their doom. They are, in fact, much in the same strait as a crayfish when he has shed his shell and is growing a new one.

The muscles that work the wings

Nearly all the active machinery for spreading the feathers, for setting these grand sails, is accumulated on the body or near it. The muscles that lower the wing or raise it spring from the breastbone, and the former partly also from the clavicle or merry-thought. The muscles that straighten the arm arise from the head of the coracoid bone and the anterior end of the scapula. From the latter point comes the triceps, the most important. It lies behind the humerus, tapers down, and passes into a tendon at its further end. All the weight of these muscles is near the body. When the triceps and its coadjutors contract and straighten the elbow joint, a great deal of passive machinery is set to work, the bones of the wing straighten into line, the flight feathers expand, and in a moment the bird is under full sail. Thus all the heavy active machinery (the muscles) is massed upon the body or quite near it. Further out upon the wing are only minor muscles directing minor movements. By means of elastic ligaments and tendons (unlike muscles, for they have no activity of their own), the active machinery at the centre controls the outlying passive machinery. This concentration of the weight at one place much facilitates flight.

Plumage and song

If what I have said about feathers were all that is to be said, if they were only a part, a very efficient part, of the splendid machinery of flight, they would only be half what they are. A bird is not only a flying machine and a physiological masterpiece, he is, in many cases, a thing of beauty, and his beauty depends mainly on his feathers. His grace and shapeliness are due largely to them. For his beauty of colour he depends on them almost exclusively. All this splendour has to do with mating. The cock bird must somehow captivate the hen bird. He may, as many of the sober-coloured warblers do, charm or at least attract her with the richness of his song. If song has been denied him, he must display whatever he has of beautiful plumage. It rarely happens that a bird is strong in both ways—that he can appeal very forcibly both to the eye and to the ear of her whom he wishes for his mate. The brilliant in plumage are dumb or but poor songsters. The goldfinch is a notable exception. In some cases the hen bird equals or nearly equals the cock bird in beauty. When this is so, we find that she is completely concealed as she sits upon the nest—the kingfisher, for instance, or the woodpecker—and so does not need to be protectively coloured. Cock birds may run risks and, indeed, if one meets his death during the nesting time, it nearly always happens that another soon appears to cheer his widowed mate. The species is the gainer by the gorgeous plumes of the male and his far-resounding song, for thus is brought about the pairing of the best with the best. Besides, there is need of recognition marks and call notes. No longer sedentary like their reptile ancestors, but spanning nearly half the globe in their migratory flights, different species, very much alike in plumage, often flocking together in their winter home—for this new life of voyage and travel, new means of keeping the species together were wanted. Song and all the grandeur of plumage seem to have had their origin in this need. The nightingale proclaims that he is in the copse, and the hen is bound to hear him and recognise him. The peacock is unmistakably a peacock. So we have call notes and recognition marks, though each, for purposes of courtship, has been ennobled till its humble origin may easily be forgotten. And there is a further development, especially in the matter of song. Delighting in the exercise of their powers, the robin and the thrush and many others too will sing when, apparently, their own society is all they want, when the mating time is past and to come, and they merely sing, as a quaint poet says, "for the happy they feel inside." The care they take in pluming themselves suggests a pleasure in their prime condition and smartness, at all seasons save when the moult comes and reduces them to a comparatively depressed and dishevelled state.

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[1] See Mr Trevor Battye's book, *Icebound in Kolguev.*

The colours of feathers

And now for the colours of feathers. All colours are due to the breaking up of white or transparent light into the various coloured lights of which it is composed. When the breaking up is due to rain-drops, each acting as a prism, we have a rainbow, showing all the colours of the spectrum. A pigment in a paint-box reflects one colour and no more, and this colour remains, however we may pound it. With a prism there is no such permanence. Crush a glass "drop" from a chandelier and we shall not get from the fragments the colours of the spectrum. In every case colours must depend upon the structure of the object which sends the light, the waves of ether, to our eye. And yet, for practical convenience, we may distinguish the structural colours due to the breaking up of the light by the feathers' horny coating, and the pigment colours, which no hammering can destroy, since the minute particles of the pigment remain unaffected.

The black, brown, red, yellow or greenish-yellow in a bird's feathers may be due to pigment alone. Only in one bird, the Touracou, is green, so far as is known, a pigment colour. Blue and violet are due to pigment aided by the structure of the feather. If you hold a blue feather up to the light so that the rays pass through it, it is no longer blue, but a dull black or grey. Hammer it and all the blue will vanish. Put green to the test, hold it up to the light, and with the one exception just mentioned, it will turn out to be a pigment-structure colour. A green feather from a parrot, if hammered, becomes yellow, the colour of its pigment. On the other hand, you may hammer a red feather and the colour will remain. Hold it up to the light and look through it, it will still be red. And so with some yellow feathers, but not all. In the Pitta or Ant-thrush it depends on structure, without, as far as is known, any underlying pigment.

No blue pigment has been found in any bird's feathers: that which a blue feather contains is black-brown or yellow. The blue as we see it is due to the structure of the horny coating which encases the pigment. The feather bears a number of small polygonal cones lying under a thin outer sheath: down the surfaces of these cones run extremely fine ridges and it is believed that to these the colour is due. No doubt they somehow break up the light rays. But how they act in combination with the underlying pigment, Dr Gadow does not explain in his admirable paper on the colours of birds,[1] nor can I get any light on the subject. Violet and green feathers have no cones like these, but there are long thin ridges lying close together and, probably, these act in the same way.

Iridescent colours

We now come to the most beautiful colours of birds, depending on structure alone and changing through part of the series of the spectrum as the point of view is changed. These are sometimes called subjective, on the ground that they have no outside or objective existence. But whenever we see colour, it is due to a ray of light reflected from some external object falling upon the retina of the eye. The retina, thus stimulated, sends, by means of the optic nerve, a thrill to the brain. And this thrill produces in the brain the consciousness of colour. There must be an outside object, the stimulus of light from it, and the resulting consciousness. It is not correct, therefore, to label one set of colours objective and another subjective. The term iridescent colours is at once correct and poetical. Iris was the goddess of the rainbow, and as these colours, dependent on structure alone, follow one another in the true order of the spectrum, we are right in calling them prismatic or iridescent in the strict sense of the word. The barbules of the feathers which show iridescent colours have a transparent horny covering. The surface is either perfectly smooth and polished or finely waved or irregularly dotted. Dr Gadow holds that this transparent sheath acts like a number of small prisms.

No other birds show these rainbow hues so splendidly as the humming-birds. They can boast of changes from bronze-red to golden-green, to green, and, it is said, on to blue and violet, though I have not myself seen this. They will run through part of the series of the spectrum but not the complete series, changing as you hold the bird and move it to and fro. There are no browns, or greys, or blacks intervening, only the colours of the spectrum, and they come in the right order. We are bound, then, to believe that they are prismatic and that the feathers of these humming-birds bear very minute prisms. But why is the series incomplete? It has been suggested that the prisms overlap, and that the colours from two neighbouring prisms combine and produce white or transparent light. The humming-birds are not alone in producing iridescent colours, though in this respect they surpass all others. The Bronze-winged Pigeon bears upon his wing a beautiful patch of colouring that shows prismatic changes. Reptiles too can boast of iridescent colours. When the sun falls upon the Reticulated Python at the Zoo, blues and greens and yellows shift about his coils.

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[1] *The Colour of Feathers affected by Structure*, Proc. Zool. Society, 1882. See also his article on *Colour* in Prof. Newton's *Dictionary of Birds*.

White remains to be considered. It is due to the light being broken up and reflected an infinite number of times. There is no pigment. To this breaking up of the rays is due the whiteness of snow. And if transparent glass is crushed it forms a white powder.

Colours, then, we divide into pigment colours, pigment-structural colours, and the iridescent, depending on structure alone. Not even flowers can boast of such brilliant hues as birds and they have no prismatic effects. They excel, however, in softness of colour. And what of mammals, from the Duck-billed Platypus up to man, the crowning glory of them? In point of colour, mammals have little to show. Hair is in mammals what scales and feathers are in reptiles and birds, and, for colour display, hair is a poor thing.

Having such beautiful colours for the admiration of their mates, and such markings for purposes of recognition, birds must, of course, have good eyesight. But their greatest keenness of sight is wanted for other purposes. A vulture does not, as used to be said, "scent the carrion from afar." Experiment shows that he can scent meat that is wrapped in paper only from a distance of a yard or so. Soaring high aloft, exploring the plain with his eyes, he descries the carcase and descends upon it. A Solan Goose from sixty feet above spots a Sight fish just beneath the surface of the sea, and descends vertically upon him. A gull, if you throw him a biscuit, picks it out easily from the maze of foam. If he does not, it is because he sees it is biscuit, and having had enough of such things, will be content with nothing but fish or meat. Small birds practise their keenness of eye all day long, picking out minute grubs from the ground or from tree bark. Keenness and wariness are often combined with a strange stupidity. In Spain I was only able to get near a flock of flamingoes by using a stalking-horse and crouching down in concealment at his side as we waded, my Spaniard and I, through a mile of water. The horse, with his leg tied to his fore-foot, looked as if he were eating, and did eat if there were any water weeds available. Thus screened, we got within thirty yards of the large flock of flamingoes, the foolish birds not noticing that the horse had two extra pairs of legs. But the dulness in such cases is hardly a dulness of sight.

Hearing

The sense of hearing is no less acute. The shore shooter must not only avoid being seen, but also being heard, by the curlew, who stands sentry not only for himself and his kin, but for all the other shore birds. The thrush hears the worm moving in the ground. The bird's ear has great power of discrimination. He knows the call note of his kind, and picks it out from all the other cries and songs with which the woodland rings in spring-time, though, when two species have very similar notes, colour may come in to complete the distinction. It is true that Golden Plovers and others are taken in by imitations of their cries that are far from perfect, but these are hardly the cleverest of birds, and it may be that they are attracted by a sound that is half novel, half familiar. To sight and hearing the bird trusts mainly, to the sense of smell but little. Indeed, the situation of his nostrils at the base of the upper bill suggests that they are only of minor utility. In one bird only, the Apteryx, do the nostrils open at the tip of the bill. The openings are very small, and it has been imagined that he trusted more to his sense of touch, to the long sensitive bristles at the base of his bill that suggest a cat's whiskers.

But some experiments recently carried out in one of the islands set apart for the preservation of the native animals of New Zealand have made it more than probable that his scent is very keen. Some shallow buckets in which were earthworms under four inches of earth were put near a Kiwi, as the Maoris call the Apteryx. He at once became excited, scratched up the earth, and ate the worms. But whenever buckets containing earth but no worms were presented to him, he was utterly indifferent. It may be suggested that he heard the worms moving, but the exceptionally large size of the olfactory lobes of his brain makes it far more likely that he depends upon his sense of smell. It is a wonder that his nostrils do not get choked with mud. But it will not do to jump to the conclusion that in other birds the position of the nostrils at the base of the upper bill is a special adaptation to prevent clogging.[1]

Lungs and air-sacs

A bird's senses are keen if we except that of smell, and there is no dulling of the senses through want of vitality. He lives at what for us would be fever heat, having a first-rate breathing apparatus to maintain his remarkably high temperature. And yet his lungs are extremely small. According to measurements that I once made, their cubic content in a pigeon is no more than one half-inch. But their efficiency must not be measured by their small size. They open out into great air-sacs, which enormously increase the lung power. When the bird inhales, the air rushes through the lungs to the air-sacs beyond them, so that though the lungs are small and inelastic, the oxygen of the air is brought very near to the blood-vessels which carry on the work of respiration. The lung consists of a great number of little tubes and pouches, among which ramify endless small blood-vessels called capillaries. From these small tubes and pouches the air cannot be exhaled that fresh air may take its place, any more than it can in the case of the human lung. But when the bronchial passages are filled with air rich in oxygen, an interchange of gases takes place. The air in the little pouches is charged with carbonic acid gas, the fresh air with oxygen.

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[1] On the Kiwi's sense of smell see Mr W. B. Benham's letter in *Nature*, July 5, 1906.

When different gases are thus brought into contact with one another, an interchange begins at once. And in the bird there is reason to believe that it is very rapid, the fresh air being brought close to the doors, so to speak, of the little pouches. And it must not be forgotten that in birds exhalation, and not inhalation only, brings a fresh supply of oxygen. The air in the air-sacs has reached them by passing through the lungs, but in its rapid transit it has parted with but little of its oxygen. When it is driven from the sacs it re-enters the lungs, if not quite in its first freshness, yet still fit for the work of oxidation. Much the same thing takes place, as I have said, when a snake breathes. The hinder end of his long lung is only a membranous bag. When he exhales, he drives the air from this hinder part, and so supplies the operative part of his lung with oxygen. But his lung is but a poor one, and oxidation in him goes on slowly. The bird's lungs, on the other hand, are most efficient, and the fact that exhalation floods his bronchial passages with fresh air practically doubles his rate of breathing. Presently I shall give some figures to show the rate of respiration in birds. But I wish before going further to give some description of the celebrated air-sacs (fig. 62, p. 118). There are nine in all. There would be ten, had not one pair that lie between the clavicles become united. The lungs lie close under the backbone, and immediately under them come the air-sacs. But the lungs are of no great length, and extend back only to the kidneys. The great abdominal air-sacs stretch out far beyond. If a freshly-killed bird is laid on its back, and by means of a blowing-tube air is forced down the windpipe and the sacs inflated, the whole abdomen of the bird will be seen to rise. To get a good view of the air-sacs, lay the bird on its back, having first inflated the air-sacs and tied up the windpipe to prevent the air from escaping. Then cut away the middle of the breastbone, near to the keel on either side, and very carefully move the entrails. Then the extremely delicate air-sacs will be seen, and beneath them the scarlet lungs, with openings debouching into the sacs.

Now that I have described the machinery, I will put down some

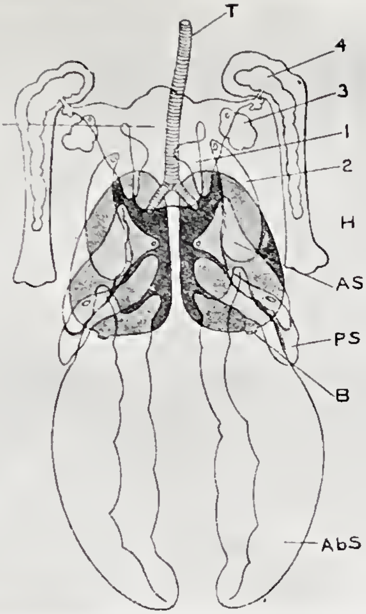

FIG. 62.—Diagram of Bird's air sacs (after Heider). The lungs are shaded dark. Abs, abdominal sac; AS, anterior thoracic; B, entrance of bronchial membrane; H, humerus; ICS, inter-clavicular sac, surrounding trachea (T); 1, 2, 3, 4, its extensions (2 opens between the pectoral muscles): PS, posterior thoracic sac. The small cervical sacs at the base of the neck are not shown.

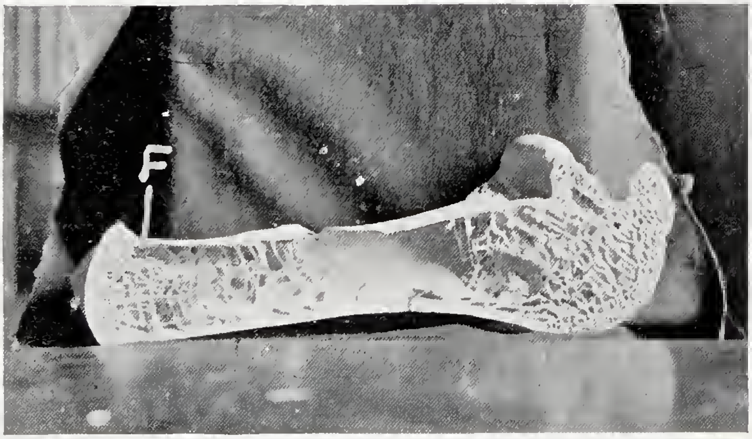

FIG. 63.—Left thigh bone of Ostrich. Rather less than one-third real length. The bronchial membrane enters near F on the hinder face, and lines even the small cavities among the fine network of bone that buttresses the outer walls.

notes I have made on the rate of respiration.[1] It varies much in different species. When a bird is lying on his breast, his backbone can be seen to rise and fall with each breath. The swan in figure 85 (p. 153) could not possibly move his breastbone, since his weight rests upon it. When a bird is standing still, the lower part of the breastbone, near the legs, moves visibly. But a small bird that never ceases hopping about presents difficulties to the observer.[2]

	Respirations per minute.
Pelican No. 1	5-6
,, No. 2	7
,, No. 3	9
,, No. 4	11
Griffon Vulture	9
Forster's Milvago (a small kite)	9
Blackbird	39
Redvented Bulbul	48
,, ,, shortly after	60
Ouzel	34
,, soon after	50
Canary, not far short of	100

The slow breathing of the large birds is remarkable. Doubling it for the reason given above, we get 10-12 for the slowest breather of the pelicans. A man when sitting takes, according to Huxley, 15-17 breaths per minute. Certainly this is not an over-estimate. It seemed to me astonishing that pelicans should be able to keep up the animal heat proper to birds, breathing in this sluggish fashion, so I took the temperature of one and found it to be 104 degrees. The bird at the time was taking about 20 respirations per minute. The application of the clinical thermometer hustled and flurried it, so that it exceeded its normal resting rate, but there is no reason to suppose that its temperature had as yet risen in response to the increased rapidity of breathing.

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[1] See also Schaefer's *Physiology*.

[2] In the next chapter I discuss the bird's method of breathing during flight. See p. 153.

Temperature

Birds generally have a high temperature, and as a rule it is higher among small birds than large. Being so small, their exterior so near to the vital organs within, it is most important that the fire should burn bright and prevent a fatal chill at the seat of life. Here are some temperatures taken by various observers, most of them averages from several trials:—[1]

	Degs. F.		Degs. F.
Great Tit . . .	111.2	Turkey . . .	109.0
Swift . . .	111.2	Pheasant . . .	108.7
Fieldfare . . .	110.6	Fowl . . .	107.9
Guinea Fowl . .	110.0	Sparrow (curiously low)	107.8
Redwing . . .	109.9	Heron . . .	105.8
Yellowhammer . .	109.8	Pigeon . . .	105.6
Duck . . .	109.1	Ostrich . . .	99.2

Dr E. A. Wilson found that the temperature of the Emperor Penguins in the Antarctic regions ranged between 99 and 101.

Even the lowest of these temperatures are high. We must attribute the fact to the large appetites and fine digestive powers of birds, and to the excellence of their breathing apparatus. It is a grand thing to send the thermometer up to 111.2 without being in a fever. It means a very high vitality.

Regulation of temperature

So far I have considered only the keeping of the temperature up to the normal. But how, during hard exercise, is it to be kept down? Much deviation either one way or the other would be fatal. With man, perspiration, or, rather, the evaporation that follows it, cools the body and keeps off fever, the lungs undertaking only a little of the work. Once the body has been exhausted of its available moisture through long exposure to a burning sun, if there is no water to drink and so replace what has been lost, raging thirst sets in. It is known, too, that a man can stand a very high degree of heat—Drs Fordyce and Blayden were none the worst for 260° F.—as long as the surrounding atmosphere is dry. But fancy getting into a bath at this temperature—48°, that is, above boiling-point! On the other hand, when there is perspiration, and evaporation goes on freely, the man is encased all over in the cool and close-fitting jerkin of his own perspiration, so that he does not come into contact with the surrounding air. In the damp air of a hot-house there is little evaporation, and the heat is oppressive.

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[1] From Schaefer's *Physiology*.

Now, a bird has no sweat glands, and so does not perspire. Like a true reptile, he has an absolutely dry skin. There must be some other means, then, of keeping temperature down, and, no doubt, the work is done by the air-sacs, which have a far greater capacity than is required for breathing alone. All the air that is breathed forth by the bird is as warm, or nearly so, as the bird's own body, something over 100°, that is. Supposing, therefore, the air to be at 80°, the bird will be greatly cooled by raising a large amount of inhaled air to, say, 100°.[1] But what if a bird happened to be, like the two doctors I have mentioned, in an oven or heated chamber, with the thermometer standing at 260°? It might be thought that he would have no means of keeping his temperature down, and would die of fever. But it must be remembered that birds drink considerable quantities of water—no water within reach, no birds. In the Sahara birds of prey are hardly found, the jackals do the scavenging. Vultures being active only during the day cannot visit the oases where alone water is to be obtained, and, therefore, the desert is no place for them. Well, birds drink freely, and the water must somehow be got rid of. Now their kidneys secrete very little water; their excrement is remarkably dry. There is no perspiration through the skin. The water must, therefore, pass from the lungs in the form of aqueous vapour. In other words, there is evaporation, and evaporation always removes heat. The earth grows cold on a clear starry night when it goes on freely. Here, then, is the chief means by which a bird keeps down his temperature during exercise. But some heat is lost, of course, by conduction, as it is called, when the air comes in contact with the bird's skin. The apteria or bare tracts may be useful for this purpose. During rapid movement through the air they may play an important rôle in this way. Still birds, like a good many mammals (dogs, for example), depend mainly on respiration to prevent the blood from rising to fever heat. In man evaporation takes place mainly from the skin, and to a less extent from the lungs: in birds it is from the lungs alone.

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[1] You can raise the mercury in a thermometer from 80° to 89° by breathing on it.

As yet I have said nothing about the machinery by which temperature is regulated. In man the arteries are under the control of nerves that spring from the *medulla oblongata*, that has its place below the cerebellum (fig. 40, p. 84). By means of these nerves the blood is sent where it is wanted. Regulated by these nerves an artery contracts or dilates, is scantily or richly supplied with blood. There is a prompt and sufficient influx wherever it is wanted, though the whole volume is not nearly enough to fill all the veins and arteries when they are dilated. Hence the reaction when your hands are chilled by snowballing. They soon get hotter than they were before we began, and the increased warmth is due to the rush of blood to the part of the body where it is most in request. There is no doubt that similar machinery exists in the bird.

Hollow bones

From the subject of breathing and the regulation of temperature, we naturally pass on to consider the hollow bones of birds. It is a commonly held opinion that all birds have their chief bones hollow: "So flight is not incomprehensible," I have heard it remarked. But the swallow, who for speed and balance and sudden acrobatic turns has few peers, has all his big bones solid, whereas in the ostrich the thigh bones are hollow (fig. 63, p. 118). Another fact of which most people are unaware is that the bronchial membrane extends into the cavities of the bones, and that the air in them has passed through the lungs (figs. 63 and 75, pp. 118 and 144). The foramen, where the membrane enters the bone, can be seen. But these cavities cannot be used for breathing in the ordinary sense, since the air cannot be expelled at will. However, when cool air rushes into the lungs and air-sacs, the warm air in the hollow bones, if at a lower level, will, being lighter, tend to rise and be replaced by some of the colder air just inhaled. When the wing is depressed, this exchange of air between the cavities and the air-sacs will go on. Thus the hollow bones will aid slightly,

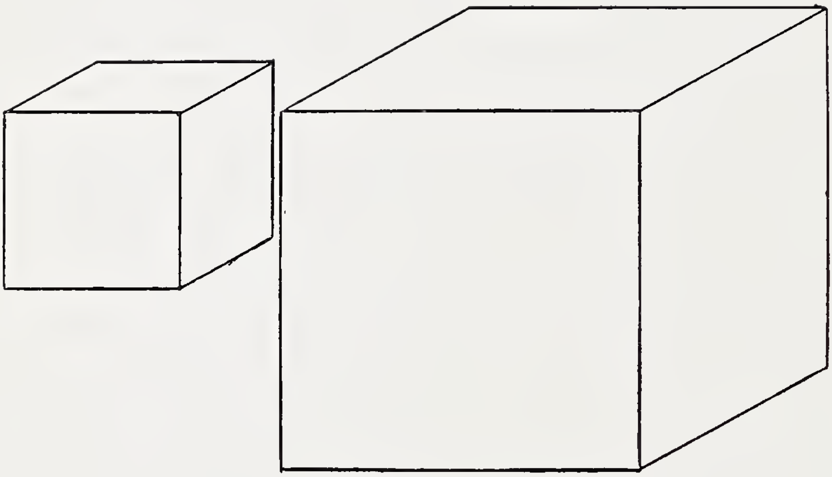

FIG. 64.—Cubes, for comparison in respect of linear dimensions, area of faces, and cubic content.

Facing p. 123

I believe very slightly, in keeping down temperature during hard exercise. This can hardly be the main purpose of their pneumaticity. There is no doubt they combine lightness and strength in a great degree, and this helps us to answer the question why they are hollow. Pneumatic bones are larger in girth than solid bones, relatively to the weight and bulk of their respective owners. This should mean greater strength. At the same time, when we compare the walls of the hollow with those of the more slender solid bones we find them thicker to some extent, but the difference in thickness is not comparable to the superiority in girth.

As to their strength, we know that the thin-walled tubes of which the Menai railway bridge is built are as strong as solid iron, and, moreover, are not over-burdened, as solid iron would be, by their own weight. We know, too, that the same thing is true of bones, since it is especially in the big powerful flyers—eagles, gannets, frigate birds—that we find a great deal of pneumaticity. Later on, in speaking about flight, I shall show that the end of the wing moves with far greater rapidity than, say, a point one-third of its length from the body, and that increase in the rapidity of wing movement increases disproportionately the resistance of the air. It follows that a long wing will be subjected to a far greater strain than a short one. We may feel sure, then, that the hollow winged-bones of birds such as the eagle (thin-shelled, big in girth) are built for strength. The reduction in weight from pneumaticity is an obvious advantage, and a far greater one for the big bird than for the smaller one.

If you take two cubes (fig. 64, p. 123), a side of one of which is twice the length of a side of the other, then the face is four times as large, and the cubic content eight times as large. Take two bones, one big in girth and the other comparatively small, then the gain in lightness through the drying up of the marrow will be far greater for the large bone than for the comparatively slender bone. So the bulky bird gains in lightness by hollowing its bones, and certainly does not lose in strength by their aeration. As to lightness, it is important to remember the extent to which aeration is carried. In all birds some of the bones of the skull are aerated. Of the long bones the humerus or upper-arm bone is most commonly pneumatic. Other bones that are frequently pneumatic are the breast-bone, the coracoid (fig. 48, p. 103), the vertebræ, less frequently the thigh-bone, shoulder-blade, and merry-thought. In the gannet I have found the wing-bones down to the fingers hollow, in the leg only the thigh-bone was marrowless. Air cavities, moreover, extend under the skin over the whole surface of the breast, probably to form an air cushion when he takes his vertical high dives from an elevation of, say, 60 to 70 feet. But the crested screamers of South America and the hornbill carry off the palm for pneumaticity, since in them it extends not only to the fingers but to the toes. Diving birds, as we might expect, have hardly any aeration; at most the humerus, among the big bones, is pneumatic. It would not do for them to be too cork-like. But it is strange that gulls and swans, which are swimmers, not divers, should be equally remarkable for absence of pneumaticity. Does the marrow in the bones enable them to resist cold better? Certainly freezing water has no terrors for them. The ostrich, emu, rhea, and cassowary have air cavities in the thigh-bones, the vertebræ, the ribs, the breast-bone, and the coracoids. Their bones are very strong and at the same time light. What are we to say of the Hornbills, most pneumatic of birds, weak on the wing in spite of it? If not so aerated they might be still weaker. But were they once great at flight? And have they lost their flying powers while retaining their pneumaticity? Their mountainous beak is a marvel of lightness, else it would make life intolerable for them. It roofs over numberless little chambers with walls of bone, the walls no thicker than tissue paper to all appearance. Let us wonder at their strange pneumaticity and leave it.

Evidently many birds gain much from having marrowless bones.[1] But what organ of the body takes over the work that is ordinarily done by the marrow? Where are the red corpuscles manufactured? In mammals the spleen is a great factory of them in emergencies (*i.e.* when much blood is lost). In birds that have very little marrow, probably more work is done by the spleen. At any rate, a bird's blood teems with red corpuscles, and its normal temperature is proof of a splendid vitality.

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[1] The hollow bones have an extremely thin lining of marrow. It is a question whether it is enough to be of use.

Locomotion on Land and in Water

Even on land birds outpace reptiles. Let us not depreciate the latter unduly. All honour to *Chlamydosaurus kingi* (see p. 89 and fig. 43), his biped gait and his short-lived sprints! Still, a barn-door chicken would, I think, be more than his match. Let those who doubt this try to catch one in the farmyard. There is no need to call in the ostrich, said to surpass the horse (though hardly the race horse) in speed, to save the birds from being defeated in a foot race by reptiles.

As to flight, that is a speciality of birds. If we except the extinct Pterodactyles, who, perhaps, rise above the reptile level and should no longer be classed with their lower-grade ancestors, reptiles cannot compete in flight. The subject of flight, by no means an easy one, I set apart for treatment by itself. But besides land and air, there are rivers, lakes, and seas. Birds have their representatives on the water, whose swimming powers are remarkable. Their methods are various. There are the penguins, who fly under water. Their fin-like wings, covered with tiny scale-like feathers, propel them through the water at great speed, the feet being only occasionally used for steering. Of all swimmers that I have seen the penguin is far the best. The shortness of his "oars" is striking when we think of the great length to which wings attain. But water offers more resistance than air, and the oar-wing has only to propel, not to lift *and* propel like the flight-wing. The large development of the penguin's breast-bone shows that he is the owner of very powerful muscles. The razorbill and, I believe, the guillemot and the divers swim in similar fashion, with their wings, that is. The cormorant uses his feet alone to propel him, striking with both simultaneously, and holding his wings motionless, though slightly lifted from the body. This position of the wings must have given rise to the idea, common among fishermen, that the cormorant flies under water. They have watched him often far down in the clear sea, and the way he carries his wings has suggested flight. But when you see him in a tank you can have no doubt that the legs are the propellers. In order to descend he heads towards the bottom and strikes hard upwards. Cormorants dive to great depths, and have been caught in crab-pots twenty fathoms down. The penguin is more at home than others under water : he swallows his fish below ; the cormorant comes to the surface and is careful to swallow his catch head first. A most important point this. I have seen a cormorant make a mistake about it, disgorge his fish, then swallow it again. I once held a post-mortem on a dead gannet which I picked up. The spiky fins of a Grey Gurnet which he had swallowed had been his death.

When floating on the surface the cormorant, the Red-throated Diver, and no doubt others, by driving out most of the air from their air-sacs, sink themselves down till only their necks are above water. Herr Gätke, the far-famed ornithologist of Heligoland, tells of a cormorant which submerged all but its neck, and so was able to catch an unsuspecting swallow which was skimming over. But a bird who meditates a long dive cannot begin by driving out his reserves of air. He must trust to strong upward strokes to force him downwards.

The swan is a very powerful swimmer, propelling himself a long way with each stroke. Like the duck he strikes almost simultaneously with both feet, one always just a little behind the other. The Indian darter strikes alternately with left and right.

Sleep-swimming

As among human beings there are sleep-walkers, so among birds there are sleep-swimmers. The time of sleep is a time of danger. The reptile retires into his hole, the arboreal bird grips his perch automatically. But what of the birds that sleep on the water ? They might drift to the land, where stoats and other enemies lie in wait for them. It must be to guard against this that ducks have the habit of sleeping with one leg tucked under the wing and the other gently paddling, so that they revolve in a circle. In summer they will often begin this in the evening when there is still some light, and this very useful aquatic form of sleep-walking can be seen.

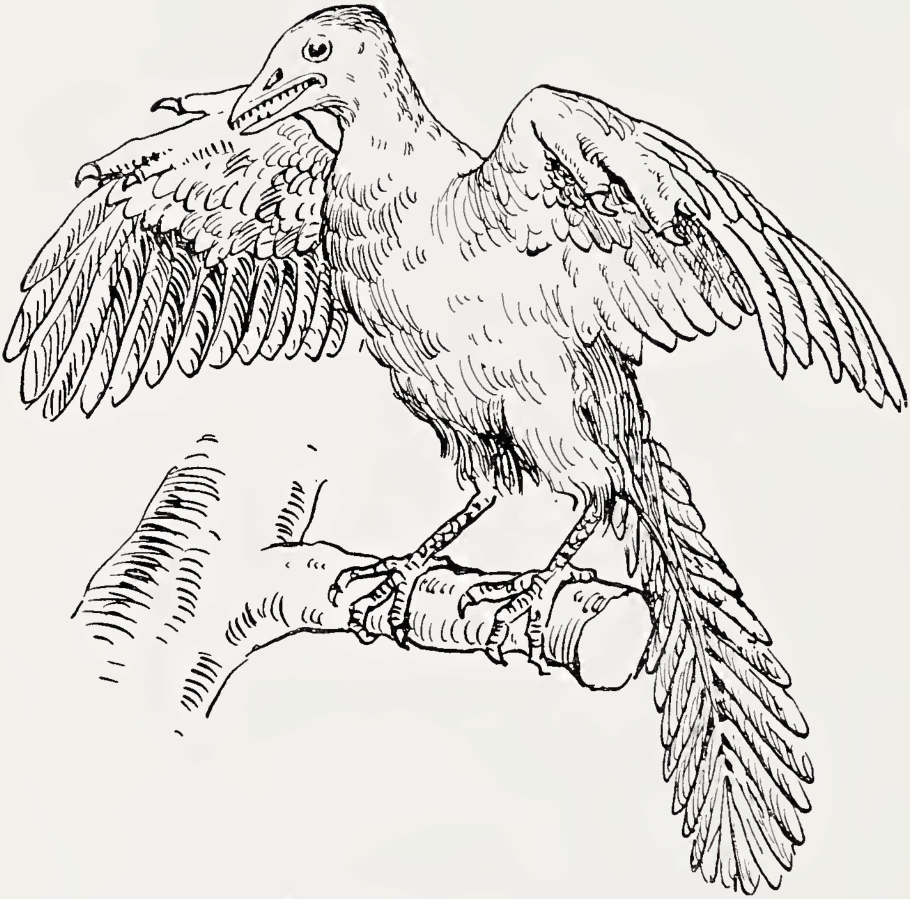

Fig 65.—Restoration of Archæopteryx lithographica. The idea of the wing after Pycraft. Actual size about that of a rook.

Facing p. 127

Archæopteryx

We have now contrasted reptile and bird, looked on this picture and on that, seen the reptile capable only of short sprints, taking his temperature from his surroundings and torpifying in cold weather: seen the bird, on the other hand, hot-blooded and full of vitality, strong on his legs; if a swimmer, a first-rate swimmer; if a bird of flight, generally a first-rate aeronautic machine. For the sake of contrast, it is good to put the perfected type beside the primitive ancestor, or such living specimens as approximate to his primitive simplicity and clumsiness. But the change from a lizard to a bird was not made at one jump. *Natura non facit saltum* is true if rightly understood. Nature moves onward, though not by infinitesimally short steps as once was thought, yet by strides of very limited length. In the Solenhofen slate (belonging to the secondary period) in Bavaria have been found two specimens of a primitive bird, Archæopteryx Lithographica, a bird beyond a doubt, and yet having very reptilian characters. Of these fossil specimens one is now at Berlin, the other—unfortunately the inferior—in the British Museum. Figure 65 represents in important points the idea Mr Pycraft has formed of the bird after much study of the two fossils. But it is not an exact reproduction of his drawing. The tail at once catches one's attention. Instead of being reduced to a pygostyle as in existing birds (see p. 107), its vertebræ extend in long succession till the bone of the tail equals the united length of the body, neck, and head of the bird. Nothing can be more suggestive of a long-tailed lizard. But the pair of appendages springing from each vertebra are true feathers. Then, the jaws bear conical teeth, a character preserved by other much later birds representing the Tertiary or even the Quaternary period to which we ourselves belong. For all that, the horny, toothless beak is typical of the bird in his most perfect development. It is light compared with the strong jawbones in which teeth, to be effective, must be set. Teeth then are a reptilian feature which has been lost by birds, though in some species it lingered long. The hand of Archæopteryx, though the fingers are three as in modern birds, is strangely reptilian. There is no fusion of the second and third digits to make a strong support for the feathers. They are the "waggly" fingers of a lizard, and they have the true reptilian number of phalanges or joints, two in the first, three in the second, four in the third digit. No. 3 in the normal bird bears only one. In spite of the agreement in number of phalanges with the reptile's first three fingers there is something to be said for the view to which the study of the hand of the embryo chick gives support, that the bird's three digits are Nos. 2, 3, 4, one being lost on either side. In any case the hand of archæopteryx is eminently reptilian, in that there is no sign of any fusion of bones. Mr Pycraft, in his restoration of Archæopteryx, represents the second and third existing digits as bound together by an overgrowth of skin and, indeed, without this, I do not see how they could have supported the strain put upon them during flight by the long wing feathers. Each finger, too, bears a powerful claw, another very reptilian point. True, many existing birds have a claw on No. 1 digit; some, on No. 2 as well, but these claws are but puny vestiges. The feathers of Archæopteryx seem worthy of an existing bird, the barbs efficiently bound together.

It is strange that there is no trace of the breast-bone. The wing being large, the breast-bone must have been well developed. A strong coracoid and a clavicle (merry-thought) can be made out. The legs and pelvis are those of a bird, and we cannot doubt that it walked as a biped. Certainly it was a bird—its size about that of a crow—and not a lizard, though its tail, hand, and teeth are lizard-like. But it cannot have been very strong on the wing; the fingers weak, and not fused together, prove that. Then its tail, on its long rod of bone, could not, like that of a modernised bird, be spread or contracted at the owner's pleasure. But, however inferior in wing and tail, it is a bird as unmistakably as the eagle that soars or the Swift that annihilates distance. It had already advanced far beyond the bird-like lizard which we can picture to ourselves flapping along the surface of sea or lake or river, unable to rise from the water, and, as it laboured onward, kicking with its feet to aid its imperfect wings.

And so I have tried to show that a reptile that seemed condemned to crawl on the earth has lifted himself on wings and become lord of the air. It is now time to investigate his art, to try to puzzle out his secret—how he supports himself on the yielding air and makes the capricious breezes his servants.

Chapter VI

THE FLIGHT OF BIRDS

Power of the Air to Resist or to Support

THERE is nothing, however wonderful, that does not cease to astonish us when it becomes a matter of every day experience and observation. The sun, as Lucretius remarked, becomes a mere commonplace thing, hardly worth thinking about. This being so, it is scarcely to be expected that we should be lost in wonder when a sparrow with a few easy wing-beats lifts himself to the roof of a house, or to the branch of a high tree. If we paused a moment to reflect, we might, in spite of the familiarity that breeds contempt, manage to feel astonished. The sparrow during his brief flight was supported on air. About air, everyone knows thus much, that it can deflect a bullet, so that a marksman must allow for wind. We have heard, too, that it checked the velocity of the bullet which the old Brown Bess sent tumbling along head over heels, and caused it to drop before it had travelled far. But our everyday experience leads us to form a low estimate of the air as an obstacle. We move about and the resistance of the air is practically nil. How, then, does the sparrow accomplish the series of jumps by means of which he lands himself on the branch where he wishes to be, having nothing but the empty air, as the poets have called it, from which to kick off? One jump, if he has any way on, will often lift him more than his own height. A wonderful achievement this when we consider what a man can do. The record high jump is a little over six feet, but the man does not raise his whole body six feet in the air. His feet, obviously, must be lifted every inch of the height he clears, but his head is, at no phase of the jump, very much higher than the bar. In clearing a hurdle, to judge by photographs, a man lifts his head and body some three feet, and I doubt whether the lift of the body is greater when six feet are cleared. The difference lies in this, that the high jumper at the moment of clearing the bar is almost in a horizontal position, his feet nearly as high as his head. Hence the advantage of the sideways jump: the feet and the body pass the obstacle to be cleared almost at the same moment.

The feat of jumping six feet is a very rare one. Even less splendid, though respectable, high jumps have been achieved only when the conditions were favourable. If the take-off is bad, the jump is a sad failure. We find this, not only in jumping, but in walking. A few miles over a sea beach when we sink three or four inches at every step is a very laborious business. When it is not a question of walking on the beach but of climbing a steep hill-side, we crave still more for solid ground beneath our feet. A steep snow slope when the sun has softened the snow is no joke. The cone of a volcano, Vesuvius for instance, or Teneriffe, where you struggle on, up to your ankles in rounded ashes at every step, is also no laughing matter. But a bird when rising has, for all that succession of jumps which we call flight, a far worse take-off than the mountaineer who toils laboriously up a snow slope or up the cone of Teneriffe. Archimedes gave up the idea of moving the world because he could not get a fulcrum for his lever. If there had been no birds, bats, or flying insects to show us the absurdity of the idea, we might well have decided that flight was an impossibility, since the air could not possibly support a body heavier than itself.

The bicyclist and the wind

And yet we have opportunities in the course of our everyday experiences of learning what the air can do. Bicyclists are always complaining of the wind, and it is curious that the "scorcher," the very man who seems most completely to overcome its opposition, complains most bitterly of it. Those who paddle along at some six miles an hour are not so embittered against the wind. Still less does the pedestrian complain of it. The old lady whom I remember in an ancient *Punch* remarking that she had never before been actually stopped by the wind, was, it turned out, charging with her open umbrella against an area railing. Let it be granted that a blizzard may almost stop a pedestrian. But then it is a blizzard and not an ordinary wind, and that helps us to understand how it is that the sparrow is able to find fulcra for his levers and rise with ease and nonchalance through the air.

An experiment of Sir Isaac Newton's

.The fact is that air offers a great deal of resistance to a body in rapid motion, while it lets a slowly moving body pass almost unresisted. Sir Isaac Newton made some experiments to prove this. He took some glass globes of equal size but unequal weights, corresponding to the figures 1, 4, 9, 16. These he let fall from a height, from the dome of St Paul's in fact, and measured the velocities when they had settled down to a uniform pace. Since there was no longer any loss or gain of velocity, the resistance of the air must have been in each case equal to the weight of the falling globe. But it turned out that the velocities of the figures corresponded to the figures 1, 2, 3, 4, whereas the weights are represented by the squares of these numbers, viz. 1, 4, 9, 16. From this Sir Isaac Newton concluded that the resistance of the air increases as *the square* of the velocity.[1] And now we can see why it is that the question of wind is a more anxious one for a bicyclist than for a pedestrian. It is because he travels fast that the air resists the bicyclist. It is true that Newton's law does not hold exactly. In the days before electricity was discovered, it was very difficult to measure the velocity of a falling body exactly. It has been found that when up to 10 metres (11 yards nearly) per second, *i.e.* about 22 miles per hour, the increase in resistance is rather less than the square of the velocity, whereas for velocities greater than this, the resistance increases at a still more rapid rate.

Weight of globe.	1	4	9	16
	↓	↓	↓	↓
Velocity.	1	2	3	4

We have now got the key to the main problem of flight. The air will resist if you only move fast enough. Double your pace and the air quadruples its resistance. Treble your pace and the resistance of the air is multiplied by 9. Quadruple your pace and the air has sixteen times its former powers. And so on.

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[1] Fig. 66, p. 133.

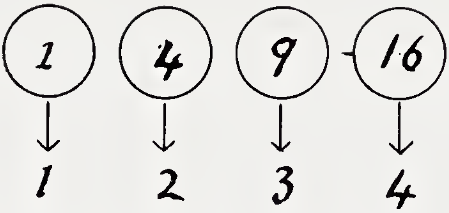

FIG. 66.—To illustrate an experiment of Sir Isaac Newton's from which he concluded that the resistance of the air increased as the square of the velocity.

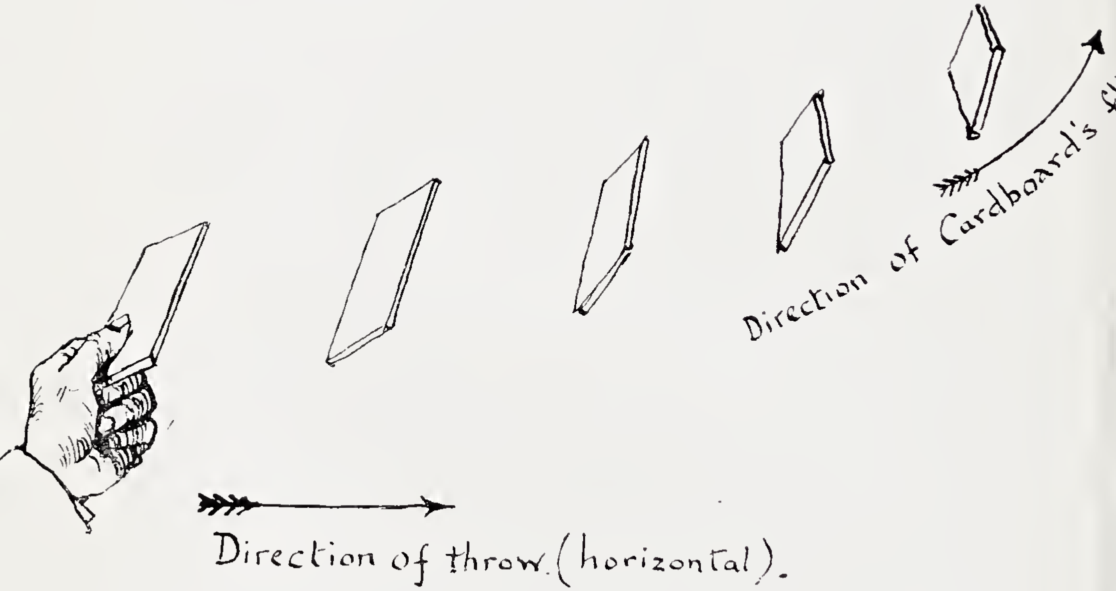

FIG. 67.—Flight of Cardboard. Hold the cardboard so that it has an upward slant, but throw it horizontally, and it will fly as in the figure.

Pace	1	2	3	4	5	10	20	miles per hour.
Resistance	1	4	9	16	25	100	400	

Resistance in the form of support

To apply this to a bird's flight. If the air can resist, it can also support, for resistance and support are the same thing under different circumstances. For clearness' sake, I will consider first the question of gliding flight, and will show how, when the bird has got up speed, the resistance of the air comes mainly in the form of support. He is travelling at a considerable pace, say at 40 miles an hour. His body and his wings form a plane sloped slightly upward. Let us imagine that the air is quite still. The wind that strikes against him will, therefore, be the wind due to his own velocity. Its effect will be the same as if the bird had no pace of his own, but, when he was poised in air with wings expanded, a 40 miles an hour wind sprang up and blew in his face. The wind due to his own velocity will, of course, check the bird's pace, but if he slopes his body only slightly upward, it will support him far more than it will retard him. A very simple experiment will illustrate this. Take a piece of cardboard about a foot in length and about 6 inches in breadth. This cardboard is to represent a bird gliding through the air. The object, therefore, is to throw it in a horizontal direction, but so that the cardboard itself while passing through the air slopes slightly upward from its back to its front edge. This is easily managed if it is held between finger and thumb by the end of its front edge, so that it slopes downward towards the back edge (fig. 67, p. 133). The cardboard will at first travel a short distance horizontally, then, as the air begins to act upon it, it will curve upwards, the gain in altitude depending on its weight, the force with which it is thrown, and the angle at which it is inclined to the horizon when thrown. As this experiment goes so far to make the main principle of flight clear, it is well to make it for oneself. A number of cardboard boxes should be broken up so as to provide pieces of different widths and weight. The light ones will soon rise almost straight in the air and sometimes come back some distance in boomerang fashion. The heavy ones will travel further, but all will curve upwards, if only when thrown

Experiments with cardboard

horizontally they are held so as to slope slightly upward. On the other hand, if, when they are thrown, the front edge is lower than the hinder, the action of the air will drive them speedily to the ground. One thing further it is important to notice. The narrow pieces, say 2 inches only in width, are very effective. It is, therefore, on the front margin mainly,[1] with which it first comes in contact, that the wind acts. It acts there with such predominant force that the cardboard often turns over and attempts to come back in boomerang style or else spins over and over. To make sure that it is the *front* edge that is forced back till overturning results, tie a very light tail to the cardboard (a piece of thread with a half inch of tape at the end). Then the way the tape winds will show the direction of the turn.[2]

Apply this now to a bird gliding. If he attains great horizontal speed by working his wings, and then puts his wings and body so that they slope slightly upward, then the air will act upon him as it acted upon the pieces of cardboard. It will support him and, but for his weight, would carry him upward. Birds are continually making use of the wind of their own velocity in this way. A few vigorous strokes give them speed, then they glide with wings outspread and maintain their level. The air checks them very little. But owing to the slight upward incline of the body, it gives them a great deal of support. And this is the next thing to make clear—why it is that the resistance of the air comes in the form of support. The upward curve described by the pieces of cardboard held on a slope but thrown horizontally, show the fact that the air does act in this way. But we cannot leave the matter without some further investigation.

Imagine a Lilliputian man, so small that when a cricket ball is

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[1] Compare Professor Langley's experiments with the "Plane-dropper," (see p. 138).

[2] The fact that the front margin is the more important, especially in very rapid movement at an acute angle to the wind, accounts for the remarkable narrowness of the wing of some of the best flyers, *e.g.* the gannet and the swift. The front part (of the wing, or cardboard) deflects the wind, and this deflected rush of air is all that reaches the hinder part. The "wind" is really the resistance of the air to the moving plane.

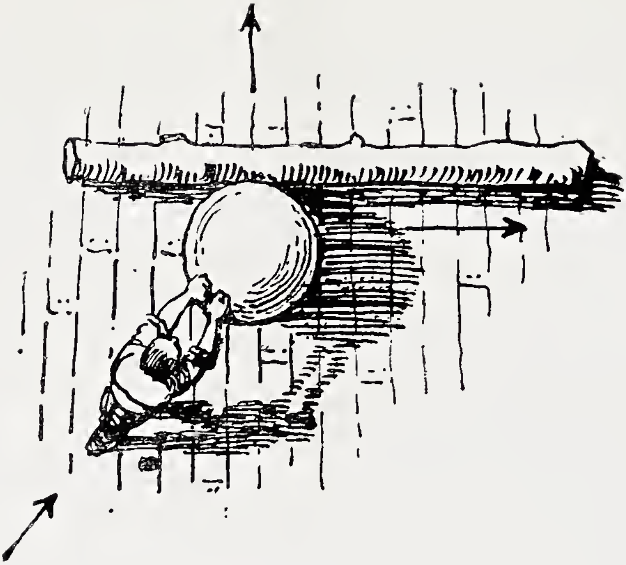

FIG. 68A.—An illustration of the Parallelogram of Forces. The arrows represent the direction of the shove, the force nullified by the log, and the actual movement of the ball.

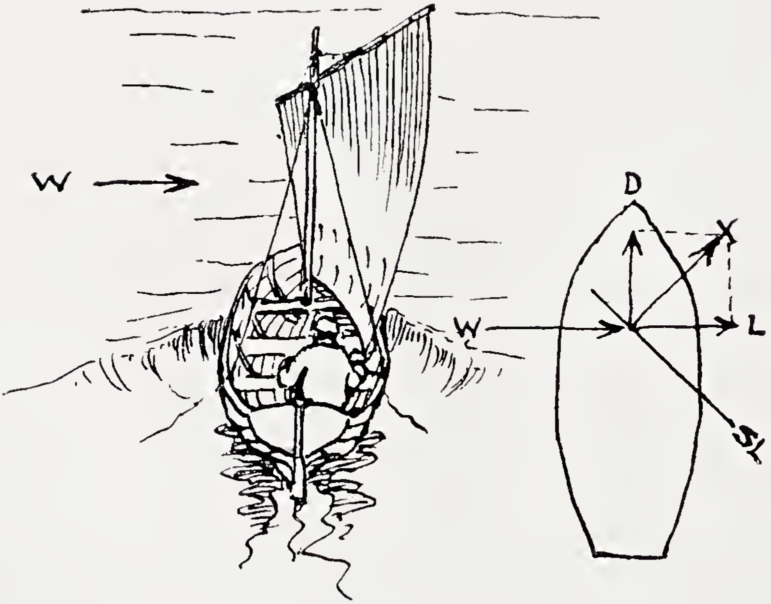

FIG. 68B.—Boat tacking—W, the wind, which acts at right angles to SL (the sail), towards X. The force X is broken up into the forces D and L.

lying on the ground he cannot see over the top of it. Suppose that he wishes to shove a cricket ball in a certain direction, but that it cannot move in this direction because of some obstacle—there is a post or something lying behind the ball which prevents it from moving. If, now, our Lilliputian and the post are on opposite sides of the ball, so that he shoves straight into it, he will fail completely, and the ball will remain where it was. But if the direction of his shove makes an acute angle with the line of the post, as in the illustration (fig. 68, p. 135), then the ball will move along the post. The same principle is called into play when a boat tacks. The wind strikes the sail and its force acts in a direction at right angles to the sail. That it does act in this direction is shown by an experiment sometimes made by disreputable small boys. Let us imagine one of them intent on throwing a stone through a window, but, not liking to show himself in front of the window in question, he stands say twenty yards off, but close under the wall of the house. If the stone goes where the young imp means it to go, the glass will fall into the room at right angles to the plane of the window, though the stone strikes it at an acute angle. In the same way the wind will urge the boat in a direction at right angles to the sail (fig. 68, B, p. 135). But to follow this course she would have to move sideways through the water. What she naturally does (like many human beings when confronted with difficulties) is to follow the line of least resistance. In other words, she travels bow foremost, except that she makes a certain amount of leeway, *i.e.* she does travel some slight distance sideways through the water. When our Lilliputian shoved at the cricket ball, the post behind refused altogether to move, and so the ball travelled only in one direction, along the side of the post. In the case of the boat tacking the principle is exactly the same, though there is some leeway. If the boat has no keel or centre-board to act as a keel, very little tacking can be done, because the sideways movement through the water is too easy. The thing to be moved must refuse to go in the direction of the push given to it. Then the force of the push is broken up or resolved into two forces, one of which takes effect, if there is freedom of movement in that direction, while

Imaginary case

Boat tacking

the other does not, as we have seen in the case of the boat tacking and the cricket ball.

Parallelogram of forces

This principle is called in books on mechanics the parallelogram of forces (fig. 69, p. 136). A force acting along CA can be broken up into two forces acting along BA DA, the lines CA, BA, and DA representing not only the direction but the comparative magnitude of the two forces. A bird is a born mathematician. The young swallow, directly he emerges from the nest, applies mechanical principles with ease and confidence, though certain niceties have to be learnt by practice. There is no flying for a bird or for any modern Dædalus without the assistance of the parallelogram of forces. This wonderful principle of mechanics can convert onward movement into upward movement (or support), can also convert upward movement into onward movement. Without this principle birds, as we know them, that with strong pulsations wing their way or mount aloft, that glide, that hover, that soar, could never have existed. They would have been doomed like their ancestors to crawl or run over the land, would in fact have remained reptiles.

Horizontal gliding

But we want to know how the principle works in this particular case when the bird is gliding horizontally with wings outspread, and his body and his whole expanse inclined slightly upward. He forms what is called an aeroplane. Let PL represent the aeroplane, L being his head and P his tail.[1] We imagine the air to be still, but there is the wind of his own velocity, *i.e.* the resistance of the air to his onward progress. Now, bearing in mind the stone thrown slantingwise at the window, you will at once see that the wind will act in a direction at right angles to the plane of the bird, in fact along the line AB. But a force represented by the line AB can be broken up into two forces, of which the lines DB and CB represent not only the direction but the magnitude. DB is six times as long as CB. When, therefore, the bird inclines himself at this angle to the horizon as he glides, the support which he gets from the air is six times as great as the opposition which it offers to his progress—a pregnant fact. If he reduces the incline till his body is almost horizontal, the opposition of

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[1] Fig. 70 opposite.

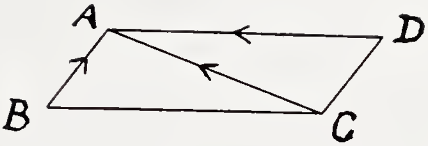

FIG. 69.—The Parallelogram of Forces.

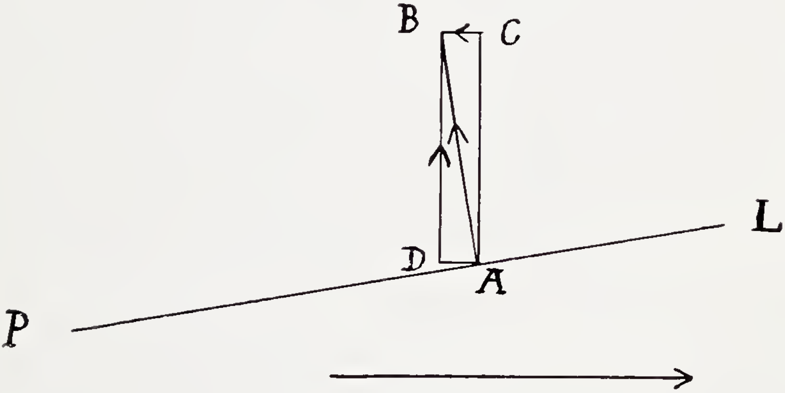

FIG. 70.—PL, an Aeroplane or Bird gliding. The arrow shows the direction of flight. The resistance of the air acts at right angles to PL, in the direction AB. The force AB is resolved into CB, DB.

the air to his progress will be even less still, and the support, *in proportion to the resistance*, will be greater. But he cannot go on indefinitely reducing and reducing the angle his body makes with the horizon. It is true that as he does so the proportion of the resistance of the air that comes in the form of support will be greater and greater. But what if the total of the resistance is reduced almost to the vanishing point? It is no use to argue that a large fraction of this total is support pure and simple. If the total is very small, a large fraction of it will not be worth much. If two men have 3d. between them to buy food with, and one takes the lion's share, say 2½d., for himself, after all he has not got much. For a bird, the angle at which he should hold himself when gliding depends on the pace which he has at command. If, like the Swift, he is capable of 80 miles an hour, or close upon it, he can afford to make the angle a very small one. If he is comparatively a slow flyer (*e.g.* a pigeon or a rook), the angle must be greater. Here, as in other walks of life, nothing succeeds like success. The bird that has the build and the skill for speed finds that the air gives him far more help than it gives to the awkward and unathletic.

Now is the occasion to give some account of Professor Langley's valuable experiments on the supporting power of the air. Later on I shall speak of his flying machine, one of the very few (.0001 per cent. or less) that have actually flown. These experiments were made with what he calls the Plane-dropper. This is a machine for flinging, with regulated velocity and at a definite angle, thin sheets of pinewood of varying dimensions. It was found, when they were flung horizontally, that, in defiance of text-books, the greater their velocity the longer time they took to fall. This is illustrated by the well-known fact that ice, which is not nearly thick enough to bear a man standing still, is yet equal to his weight if he only skates rapidly over it. When he travels quickly a larger area of ice contributes to his support during, say, ten seconds, than if he stands still for the same time. To return from ice to air. If a bird is tied by a string fastened to his legs and tossed into the air, as soon as he has flown as far as the string will let him he is no longer able to sustain himself and drops. A bird during flight requires ever fresh tracts of undisturbed air to support him. Professor Langley also found that planes whose width from front to back was small in comparison with the length of the advancing edge took longer to fall than those whose front edge was comparatively short. This agrees with the observations we made on the flight of pieces of cardboard. It has an important bearing on the subject of gliding flight. If a bird, when gliding, wishes to maintain his level, he spreads his wings to their full extent. If he wishes to descend he partly flexes them (fig. 71, p. 138).

I now pass on to the experiments that bore directly on our present subject—the angle at which a bird must set himself and the advantage of flying rapidly. The planes were set at an angle to the horizon and flung horizontally, like our pieces of cardboard, and it was found that less power was required to maintain a horizontal velocity of seventeen metres per second than one of fourteen—because a fast-moving plane can be set at a smaller angle to the horizon.[1] And so with a bird.

The bird as a kite

What I have been saying about the lifting power of the air will be much clearer if we consider the bird as a kite (fig. 72, p. 138). Why does a kite rise when the wind is blowing horizontally? Once more the parallelogram of forces accounts for it all, ignorant though most kite-flyers, whether English children or grown-up Chinamen, may be of the fact. The wind blows against the surface of the kite, acting at right angles to the plane it presents. But the kite cannot travel in this direction since the string forbids it. The force represented by the line AB is, therefore, resolved into two forces AD, AC, of which only AD takes effect. But if the bird is a kite, where is the string? The string is his momentum, the pace which he acquires by plying his wings. As long as the wind cannot carry bird or kite along at its pleasure, but meets with resistance, it has power to lift. It is essential, if the parallelogram of forces

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[1] See *Experiments in Aerodynamics*, by S. P. Langley pp. 26-47 (Smithsonian Institution, 1891).

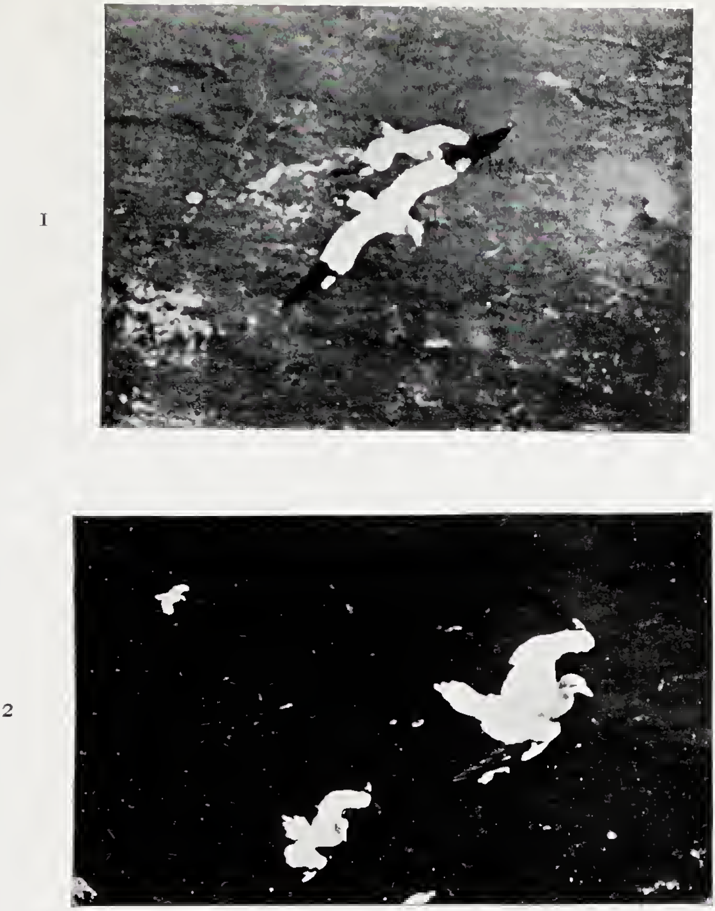

FIG. 71.—Gannets gliding—(1) with wings outstretched; (2) with wings partly flexed.

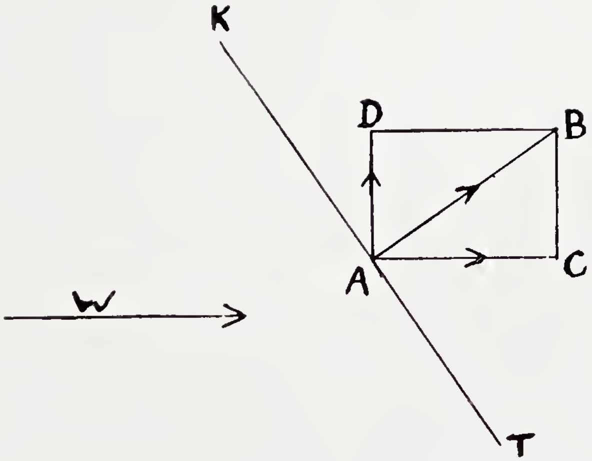

FIG. 72.—Diagram representing a Kite—KT, the kite; W, the wind, acting in the direction AB at right angles to KT. Since the string holds the kite, the force AB is resolved into AC, AD.

is to work and one force is to be resolved into two, that the object should refuse to move in the direct line of the shove. Our Lilliputian could not push the cricket ball in the line he wished because of the post lying behind it. The wind could not drive the boat sideways through the water and so she travelled bow foremost. The kite refuses to be the plaything of the wind and so the wind lifts it. The gliding bird, too, is the pig who "won't be druv," and accordingly is supported by the wind. The fact that the wind is partly or wholly due to his own velocity does not affect the principle.

Flying-machines

The modern flying machine (which is a success so far that it can rise in the air, though no means of controlling it has yet been discovered) rises from the ground on the kite principle. I am not speaking now of balloons which succeed by the help of a powerful engine in travelling against a gentle wind, but of the flying machines properly so called, machines which, like birds, are heavier than the air and consequently do not float in mere balloon fashion, but depend on their speed of movement, and which, if they halt for a moment, must inevitably descend to earth. These are true flying machines. Professor Langley's aerodrome has risen from the ground (or the deck of a boat) and flown a mile or more, driven by screw-propellers worked by a one-horse-power engine. Mr Maxim's machine, weighing over three tons, rose in the air, but its author speedily turned off the steam, knowing how clumsy his gigantic bird was in alighting. Indeed it damaged itself in descending to earth after its small and only flight, and has never essayed the air again. Both of these machines are on the aeroplane principle. They present to the air a great expanse of canvas inclined slightly upward, and when they are driven forward horizontally by screw-propellers, they fly *upward* just like the pieces of cardboard which we held slantingwise but flung horizontally. Mr Maxim's machine was provided with wheels, and was thus enabled to run along rails constructed for them. When a velocity of 36 miles per hour was attained the machine rose in the air, and, the steam being turned off, descended with a crash. Professor Langley's aerodrome, much lighter of build, so light that it cannot carry a

Professor Langley's

man to work it, has made several flights with success, landing in water—when a water-tight compartment saves it from sinking. This brief account shows the lines along which modern inventiveness is feeling its way. Its hopes are fixed upon an aeroplane with screw-propellers. In a man-made machine this is a possibility and probably the best possibility. But for a live animal such a form of machinery is out of the question. The screw shaft must revolve freely, and, therefore, cannot be welded to the rest of the machine. A bird is more than a machine. It is machine and stoker combined. Moreover in a sense it never wears out, since it has the power of reproducing itself. In the live-animal machine every part must be united organically to the whole. The wing, therefore, cannot like the screw make a complete revolution. But both bird and flying machine depend largely on what I have called the aeroplane principle: they get up great horizontal velocity, and, exposing a large surface slightly inclined to the horizon, are lifted by the air. This method of rising is practised by big, heavy birds.[1] The cormorant and gannet, when they have been fishing, get up pace and, slanting the body slightly upward, rise slowly as they go. Eagles and vultures and all big heavy flyers rise in the same fashion. They must have space. Men trap the condor by putting carrion for him in a small space walled in on three sides. When he is busy with his feast a horseman rides up, appearing suddenly from the direction of the one side that remains open. The great bird, always heavy, and now heavier after his gorge, cannot rise because of the walls on three sides of him—there is no room to rise by a gentle incline. His only chance is to dash past the mounted man, but that seems not to occur to him. So he is caught ignominiously. A puffin cannot rise unless he is able first to take a header into the air from a height. Put him in the bottom of a boat and he is reduced to helplessness. Swifts, as far as my experience goes, cannot rise from the level, their legs and toes being too weak for the initial jump. But Mr Howard Saunders, a very high authority

Big birds and their method of rising

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[1] See note at end of chapter on the question why small birds are able to rise more easily than big ones.

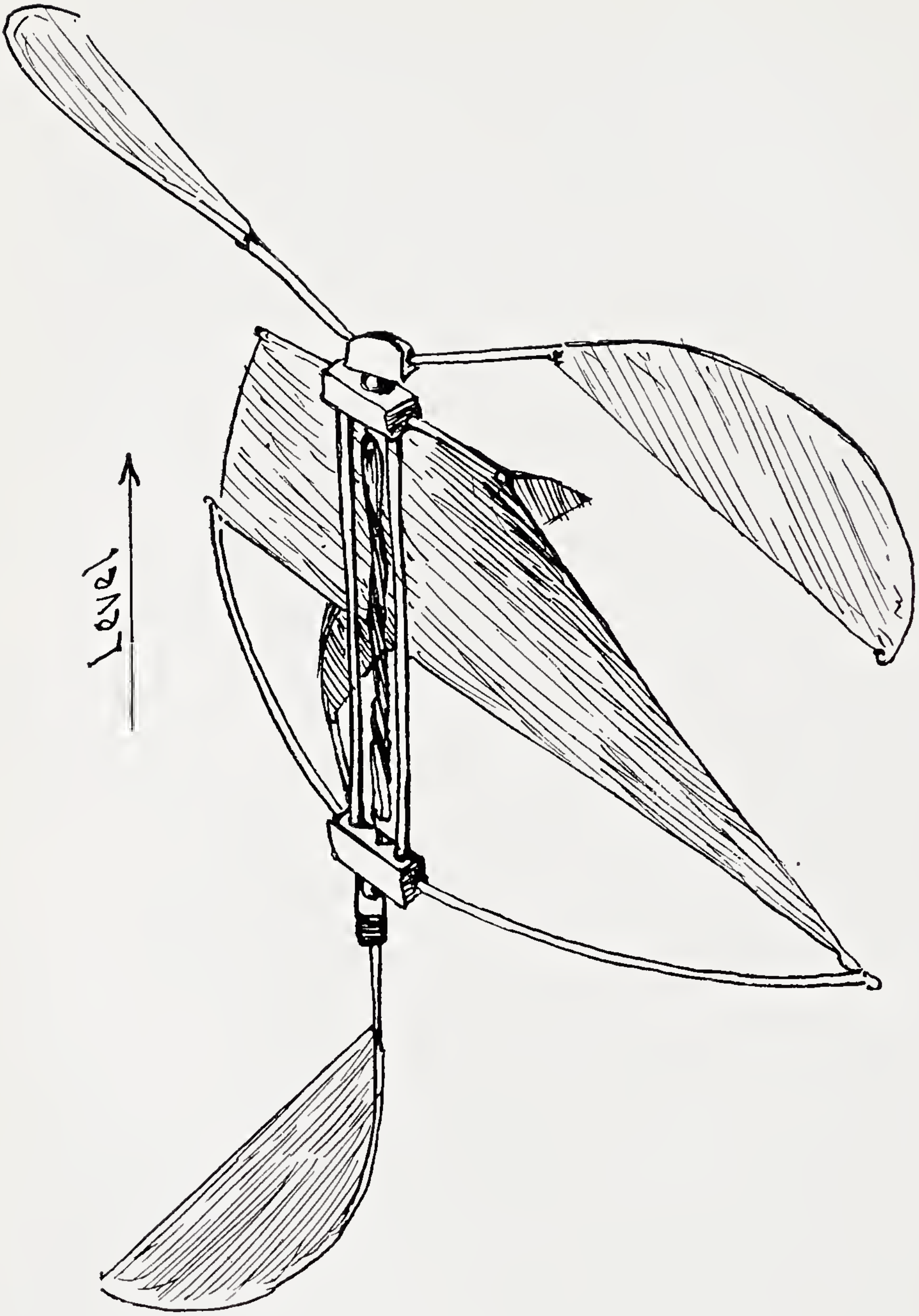

FIG. 73.—A toy Flying Machine.

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on birds, assures us that they can. However that may be, all birds, the larger ones especially, make great use of onward velocity in rising, being lifted by the air like our pieces of cardboard, like a kite, or like Professor Langley's or Mr Maxim's flying-machines.

The general principles on which these flying-machines are built I have explained, but it is well not only to read of these great efforts of engineering skill, but to try to imitate them on a small scale, in fact to make a toy flying-machine. The question of motive power is difficult. Nothing but indiarubber, as far as I know, is available, and, for this purpose, it is rather poor stuff.

A toy flying-machine

To build the machine, take a thin piece of bamboo, say six or seven inches long, and split it down the middle. Point the ends and drive them into two corks, so that a rectangular frame is formed (fig. 73, p. 141). In two other corks the arms of screw-propellers are set. I have tried making the propellers by bending shoots of hawthorn or blackthorn or thin split pieces of bamboo, and keeping them bent by means of thread tied across the curve. Tissue paper or gold-beater's skin is then stretched across the enclosed space. In the corks that carry the propellers I fasten steel wire, then pass it through holes made in the two corks belonging to the rectangular frame. Within the frame the wire is bent to form a hook. Bands of elastic connect the two hooks.[1] To form an aeroplane I drive small shoots of hawthorn or blackthorn into the two hinder corks, and by means of threads connect the ends with the anterior ends of the bamboo rods. Across this frame of thread I gum tissue paper or gold-beater's skin, and thus form an aeroplane that slopes upward from its hinder end. To set the machine in motion, hold one propeller and turn the other round; each must be turned many times till the elastic is thoroughly twisted. When you let go, the propellers will revolve rapidly in opposite directions, and, if one is left-handed and the other right-handed (notice in the figure the different slopes of the blades of the fore and aft propellers), they will combine to drive the machine forward. The sloping aeroplane will convert horizontal flight into upward flight. In fact if the construction is satisfactory in all important points, your bird will rise in air and keep a steady course. (If clumsily made it will fall to the ground and kick like a grasshopper in convulsions.) The two propellers moving opposite ways prevent it from rolling over and over as it goes, after the manner of toy butterflies. Major Baden Powell's machines constructed on this general plan, but different in detail, rise with admirable buoyancy. One of my own has been fairly successful, battering against the ceiling of a room about twelve feet in height. It is most important to reduce friction to a minimum. With this object I put a bead between the two corks at either end. Each of the four corks is faced, just at its middle part, with a piece of sheet aluminium, so that the two which bear the propellers move easily. The question of weight is also, of course, of the utmost importance. In one with a frame measuring just over seven inches in length, and with propellers having a span, between the tips of the blades, of a little over a foot, I have reduced the weight to just three-quarters of an ounce.

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[1] Very thin elastic passing many times from hook to hook.

A flying wind-mill

A very easily constructed toy—I call it the "flying" windmill—is a great help in the study of screw-propellers (fig. 74, p. 142). It consists of two windmill sails (propeller blades) fastened to a thin wooden skewer. Twirl the skewer rapidly between the hands and the apparatus will ascend to the ceiling or descend to the floor, according to the direction in which it turns. If the propeller blades are made to slope the opposite way, the upright must be twirled in the opposite direction if upward movement is to result.

A fundamental principle established

We have now taken various artificial contrivances to show how onward movement or mere resistance to the wind is converted into upward movement. First ordinary pieces of cardboard thrown in the way described. Then the kite; held by its string so that it resists the breeze, it is bound to go upward. Then the aeroplane with its upward slope, as exemplified in modern flying-machines, from Mr Maxim's giant and Professor Langley's splendid piece of mechanism, down to a toy machine weighing three-quarters of an ounce. Lastly, the "flying windmill." Each of these presenting a sloping surface to the air, as it moves horizontally or merely offers a passive resistance to the breeze, illustrates the parallelogram of forces, and in

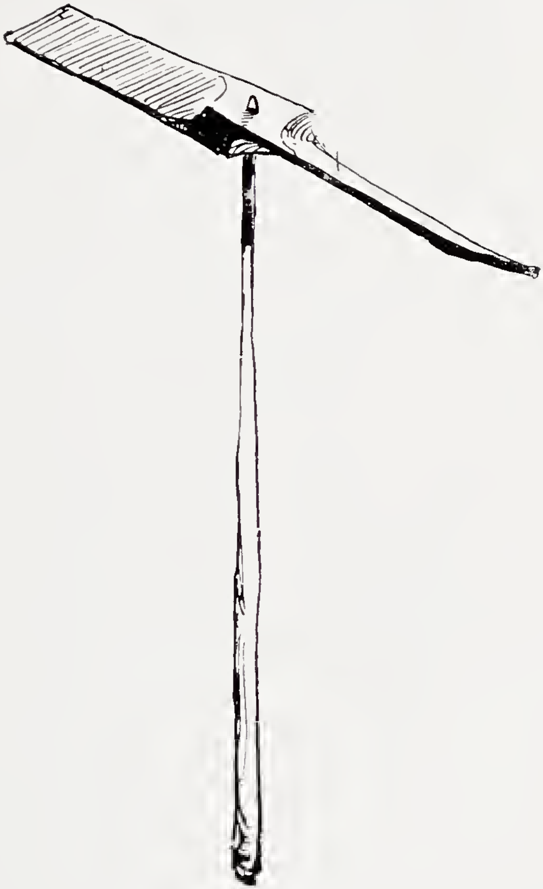

FIG.—74.—"Flying Windmill." Twirl the upright round between your hands and the "windmill" will fly up to the ceiling or down to the floor, according to the direction in which you make it spin round.

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obedience to that invaluable principle of mechanics rises in the air. Birds (notably big birds), when they start to fly, slope their bodies as the aeroplane of a flying-machine is sloped and, getting up horizontal velocity, are lifted by the wind, the wind due to their own velocity, on thoroughly sound mechanical principles. If there is a breeze blowing, they face it with advantage to themselves, as I explain further on.

How the Wing acts

I now get on to the question how the wing acts. The movement has to many people seemed like rowing. A bird is to them a very expert sculler. This view has the authority of Virgil to support it. For does he not speak, when he tells the story of Dædalus, of his *remigium alarum*, "the wings that rowed him"? In poetry this is excellent, but for us who wish to know how the bird really manages to fly, it is no use to talk vaguely about oars. A little consideration will force us to conclude that wings work on quite a different plan. When a boat, a four oar or an eight oar, is travelling fast, it is most important that each man should get on at the beginning of the stroke. Otherwise the happy moment is lost, the boat, propelled by others, moves on, and the oar comes into the chest whether a pull has been given or not. The man who habitually misses his chances is a mere passenger. But the iterated exhortation of the "coaches" as they ride along the bank, "Get on at the beginning," shows that it is no easy matter. And yet even a fast boat travels comparatively very slowly, a 'Varsity boat at about the rate of a mile in five minutes, whereas a homing pigeon with the wind to help him will keep up a pace of fifty miles in the hour. And a swift is to a pigeon as an express train is to a parliamentary. How, then, could a swift or even a pigeon work his wings as the oarsman works his oars? Imagine a bird travelling at no more than twenty miles an hour. The wing, trying to work as an oar, would be swept back by the air before a stroke could be given.

Up-and-down movement of wings

Even with the naked eye, when we watch a gull, for instance, or even a small bird, we can see that the wings in onward flight are moved up and down, not pulled after the manner of oars. What we have first to make out, therefore, is how this up-and-down movement not only raises and supports the bird but propels him.

Once more we find ourselves face to face with the parallelogram of forces. There is no getting rid of it. I will first describe the stroke or wing-beat of a pigeon when he is rising. He raises his wings over him. The backs of them may be heard hitting together as he rises scared and flurried. Now follows the all-important down-stroke, that is both to raise him and propel him. The wing strikes at once down and forward, keeping, throughout, its front edge foremost (figs. 77 and 78, p. 145).

The wing makes use of the parallelogram of forces

But the great Depressor muscle, attaching, as it does, to the front edge of the humerus (fig. 75 opposite), tends to lower the front margin more rapidly than the hinder part of the wing, so that the slope from front to back is upward (see fig. 76, p. 145).

Phases of the stroke

The front margin, in which the rigidity and main strength of the wing reside, is pulled downwards, while the rush of air against the expanse of feathers behind raises them and aids the muscle in giving to the wing the incline required. Directly the proper incline is given, the parallelogram of forces comes into play. The wind due to the velocity of the down-stroke acts at right angles to the wing (RM in fig. 76, p. 145). RM is resolved into two forces, RS raising the bird and RT propelling him. During a full length down-stroke the wings move forward, as well as downward, front edge leading, till at length the utmost limit is reached.

The up-stroke is comparatively easy. When the down-stroke is over, the elevator muscle begins to lift the front margin of the wing. As soon as the front margin is higher than the back, the wing is lifted by the wind, due to the bird's own velocity and the slight drop of the body between the strokes. So but little work is demanded from the elevator muscle which, compared with the depressor, is very feeble. In the course of the ascent the wing is flexed at the wrist, then straightened again, and, having been driven back in the course of its ascent, at length stands upright above the shoulder-joint with its front edge foremost ready for a new down-stroke. If this description is

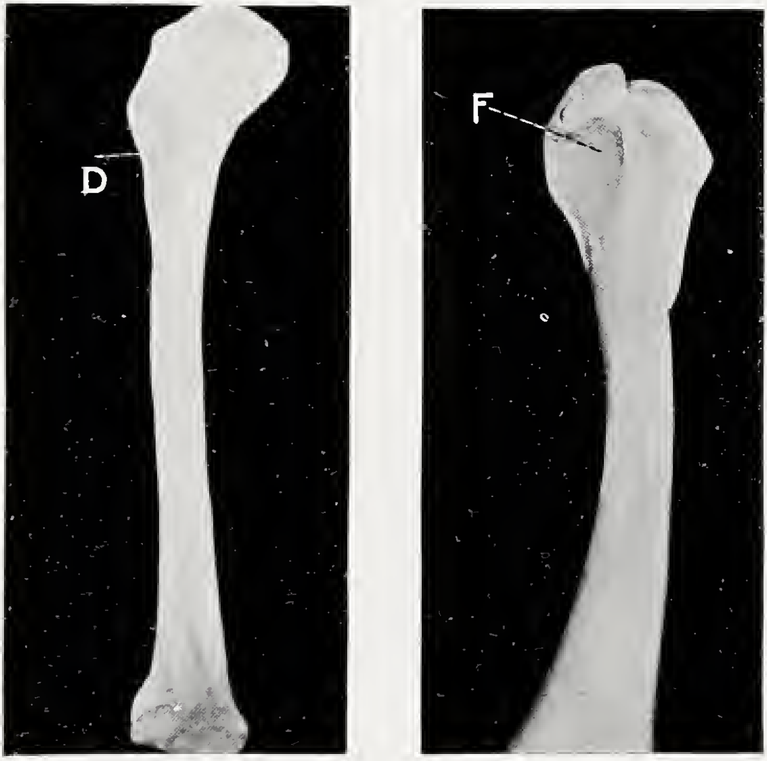

FIG. 75.—Right humerus of Eagle, a little less than half actual length—D, a flat area on the front margin of the under side where the depression muscle attaches; F, the foramen on the upper side where the bronchial membrane enters.

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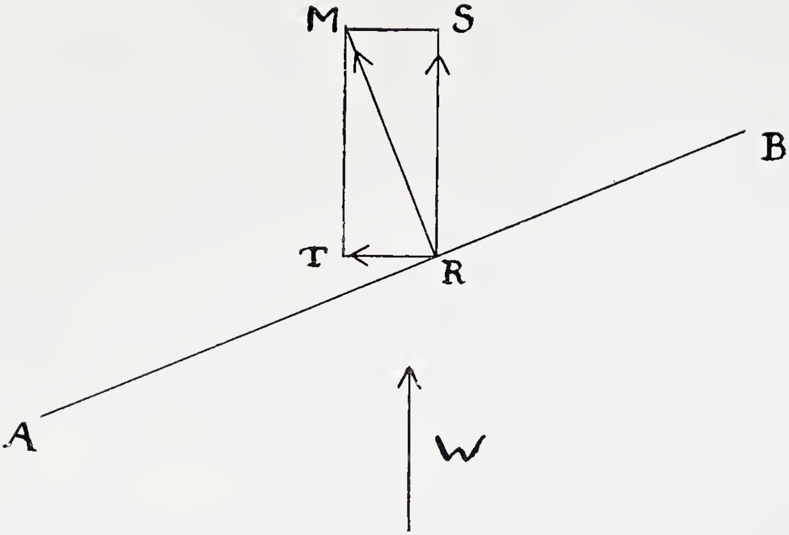

FIG. 76.—Diagram illustrating the action of the air on the wing as it descends—AB, a section through the wing from front to back; A, the front margin; W, the wind, its action represented by RM at right angles to AB. The force RM is resolved into RT, RS.

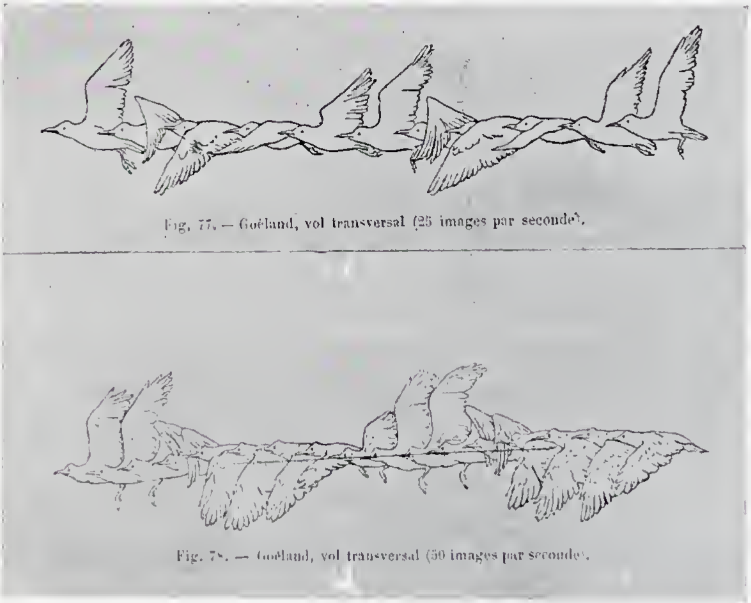
Fig. 77. — Goéland, vol transversal (25 images par seconde).
Fig. 78. — Goéland, vol transversal (50 images par seconde).

FIG. 77 (after Marey).—Gulls flying—(1) 25 photographs per second; (2) 50. Much of the down-stroke is not represented, so rapid is it.

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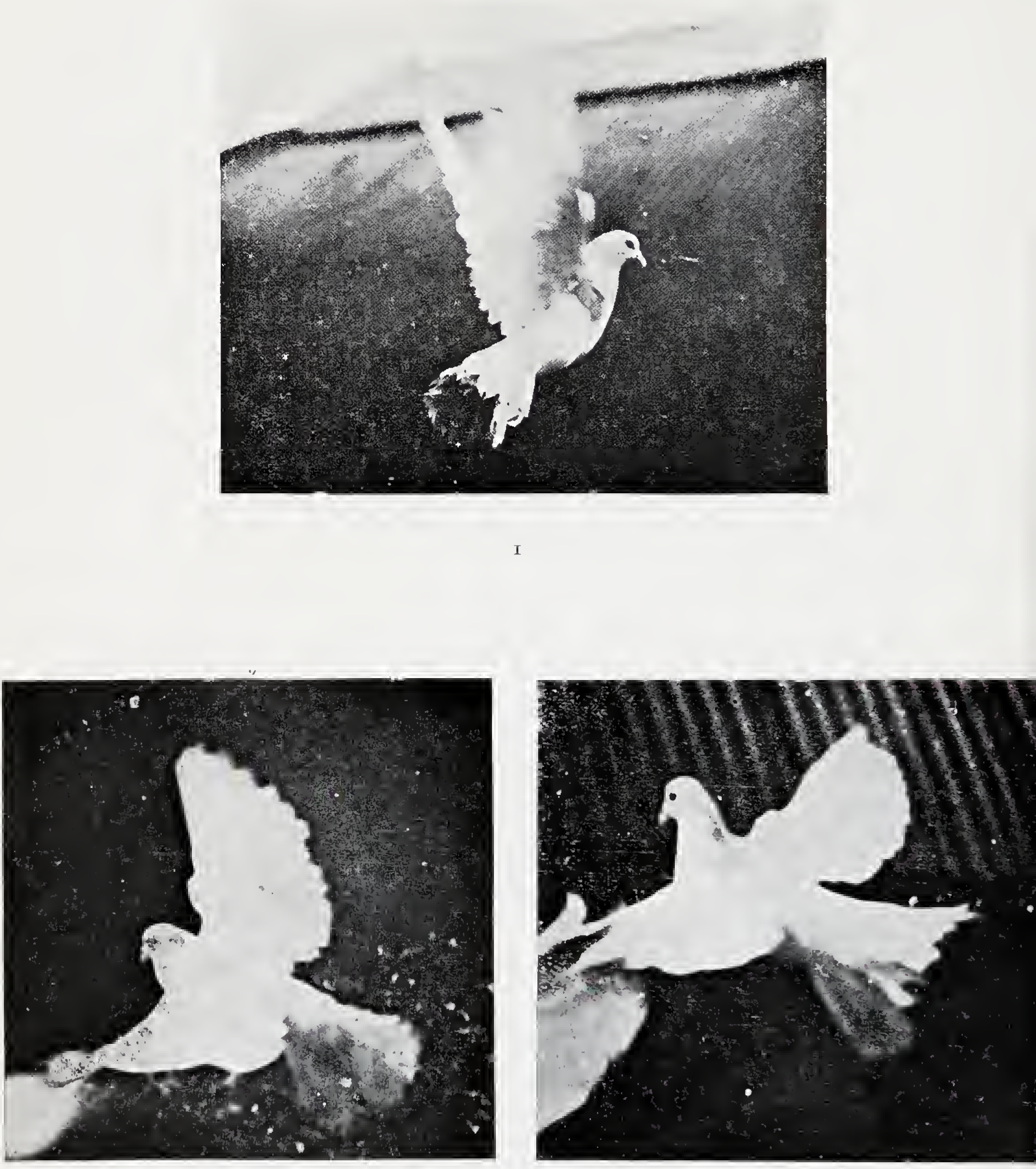

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FIG. 78A.—1, ready for the down-stroke; 2, 3, progress of the down-stroke.

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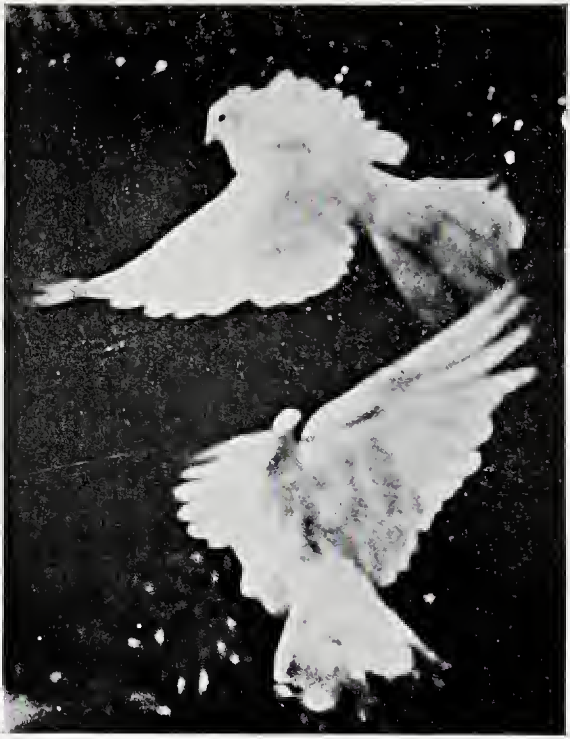

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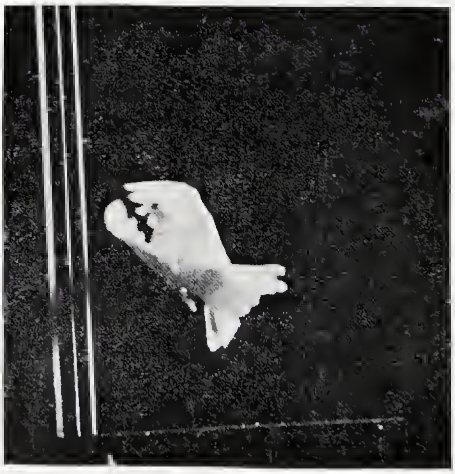

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FIG. 78B.—4, progress of the down-stroke; 5, beginning of the up-stroke.

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rather puzzling, the different phases of the stroke can be followed in the accompanying figures. Professor Marey[1] has shown almost every movement of the gull's wing, obtaining photographic images at the rate of twenty-five and even fifty per second, and these photographs of his have brought to light strange movements and positions that imagination would hardly have guessed at (fig. 77 opposite). Fifty images per second! and yet so marvellously rapid is the first part of the down-stroke that it is not shown. But we can easily supply the gap. I have myself taken a number of photographs of gulls, gannets, and pigeons flying, from which, though much more roughly, the phases of the stroke can be made out (fig. 78, p. 145.)

But it must not be supposed that birds always take these long energetic strokes, raising the wings upright above the body, then bringing them down till they nearly meet below. Some birds, it is true, for instance the ducks and their allies, always fly by means of a long wing-beat. The breastbone is long, and the depressor muscle that springs from it is long (fig. 79, p. 146). The longer the muscle, the more it can contract. Hence a long stroke comes easy to a duck. Other birds, for instance the adjutant, the frigate bird, the gull, and the tern, have a short but deep breastbone, and their ordinary wing-beat is short but powerful. The ordinary stroke of a sea-gull or a gannet is short, a fact that can easily be made out by the naked eye (figs. 81 and 53, pp. 147 and 106). Among a number of gannets, none are taking a full-length stroke. In gulls during leisurely flight a phase of the up-stroke is very conspicuous. The wing bends at the wrist, first backward (away from the thumb), then downward as our wrists do (fig. 53, A, p. 106).

The wing as a lever

We must now consider the wings as levers and settle the important question where the fulcrum is. No lever can do its work unless the fulcrum is fairly firm. We could not even poke the fire effectually if the bar on which the poker rested yielded and wobbled. Much less would the ancient Egyptians have worked their colossi along over the land if the soil had been so soft that the levers sank in deep. What I said at the outset must now be borne in mind, that the resistance of the air increases as the square of the velocity, and when the pace exceeds 11 yards per second increases even in a greater ratio. The wing, then, must be made to move so quickly through the air that at last the air balls beneath it and stops its further progress. When this happens the fulcrum, or fixed point, has been gained, and the bird is hefted up. It may seem, when we look at photographs, as if the wing reached its lowest possible point without being stopped by the air. But this is an illusion. Directly the wing finds its fulcrum, the weight (the bird to wit) is lifted, and the lifting of the bird's body brings the wing home, brings it to its lowest point, so that it has the appearance of having beaten its way down. In the same way, when a boat travels easily the motion of the boat brings the oar home to the chest of the oarsman; there is no need to force the blade through the water.

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[1] *Vol des oiseaux.*

Beneath which part of the wing is the fulcrum? Certainly beneath that which moves most quickly and which, therefore, meets with most resistance, that is, the tip and the tract near it. The fulcrum is distributed—we cannot put it at any one point—but certainly it lies nearer to the further end than to the body. It is wonderful what results come out if we compare the pace at which the wing moves at the tip and at a point near its base. Let WX, WY (fig. 80 opposite) represent the wing of a bird at different periods of the down-stroke. Let xy represent one inch. During the descent, then, little x passes through one inch of air, whereas big X passes through six inches. But since the resistance, even when the pace is not great, increases as the square of the velocity, X will meet with at least thirty-six times as much resistance as x.

Economy of power not the object

Truly the bird's wing is a wonderful lever; with the air for fulcrum it lifts and propels. But the gain from its leverage is very different from the gain which men secure by the use of a lever. Our object, as a rule, is to move some weight with less labour, regardless of the greater time required. If an oarsman had strength enough, he might use an oar with a very short handle, and, pulling this very quickly back, make his boat move more rapidly than he can with a long-handled oar which, though it

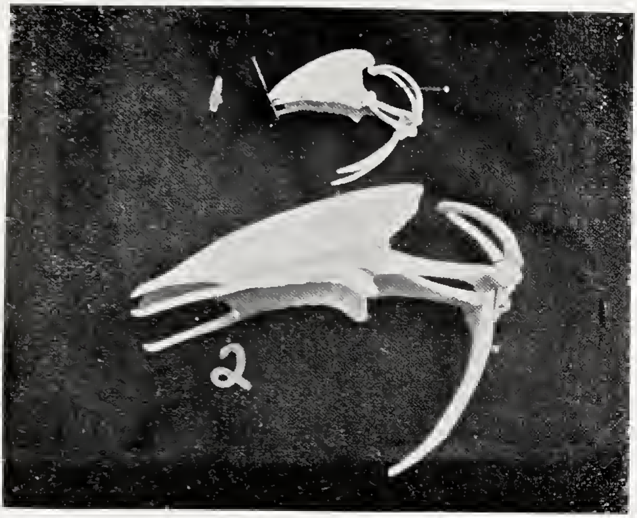

FIG. 79.—Sternum (breast bone) of—(1) Tern; (2) Duck. A short, deep sternum for a short, strong wing-stroke; a long one for a long stroke. Clavicle, coracoid, scapula on right.

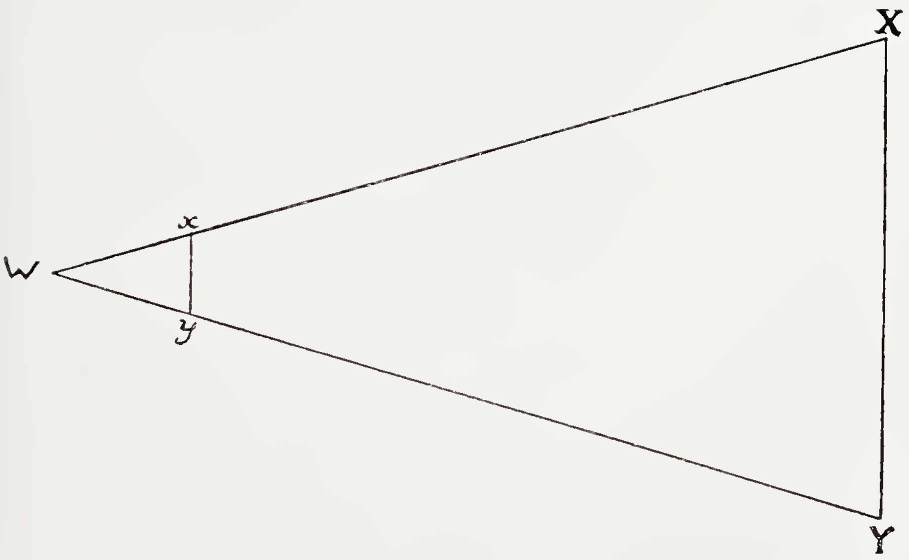

FIG. 80.—Diagram of Wing. The tip moves from X to Y, while a point near the base moves from x to y, one-sixth of the distance.

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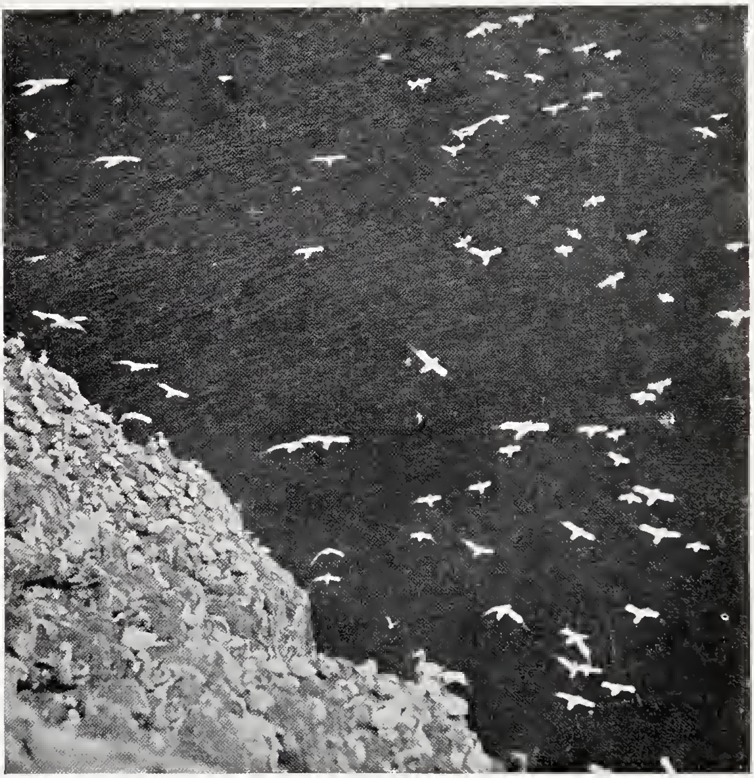

FIG. 81.—Gannets from Bass Rock, all flying with short strokes.

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reduces his labour by leverage, also largely reduces his number of strokes per minute, since for each complete stroke he has to bend forward to his full reach. The saving of labour is balanced by a loss of speed. In the animal body there are numbers of levers, and nearly all of them are of the kind employed when a sewing-machine is worked by a treadle, the power being applied at a point between the weight and the fulcrum. There is no economy of labour, but the effort required is so small that economy is unimportant. The foot that would otherwise be unemployed is made to do its share of work. It is this kind of lever, which cannot be made to economise labour, that plays so large a part in animal machinery. It produces rapidity of movement, which is the all-important thing. If the muscles are strong enough, what need to spare them? But if all their movements were slow, what poor things animals would be! The speed of the hare, and that of the greyhound that pursues him, are alike due to levers of this order. And, no less, does the wing of a bird owe its efficiency to leverage of the same kind. The great depressor muscle that lowers the wing attaches to the humerus or upper-arm bone at a point quite near to the body. The point of attachment is easily made out on the bone. There is a smooth flat place on the lower surface of the bone and towards the front edge, and this is where the tendon from the great muscle attaches (fig. 75, p. 144). The nearer to the body the power is applied, the greater the force required, but the greater the speed communicated to the wing (fig. 80, p. 146). The bird is prodigal of energy, but he gets glorious results from his machine.

Steering

Use of the tail

How does a bird steer? "Obviously by the tail," most people would answer. The tail suggests a rudder, and so it must be one. "But," said the Duke of Argyll dogmatically, "it can't be a rudder, because it is put on edgeways, and therefore it can produce no effect when moved from side to side." There is also the fact that birds that have lost their tails, a fairly common occurrence with rooks, manage to steer pretty well.

It is by no means easy to see how far the tail is used in steering. Often a pigeon will lower the left side, say, so that there is an upward incline from the left to the right side of it. He turns it *en bloc*, keeping it all in one plane, and making its whole expanse slope downwards to left or right according as it is to left or right that he wishes to steer (fig. 82, p. 148). The tail thus used must act as a rudder does, but its effect cannot be much. If the bird made the feathers on one side point almost vertically downwards, while those on the other remained horizontal, no doubt it would be a very effective rudder; but, as a fact, we never see it used in this way. Yet, in making sudden turns, it is a most important piece of gear. To convince yourself of this, it is only necessary to watch a swift, a martin, a swallow, or a peewit twisting and turning. The evolutions of these birds require a sudden checking of speed when they turn and double, and then the tail is spread to its utmost expanse at the moment when a start in the new direction is being made. For balancing, too, the tail is of the greatest use, as I shall explain later on.

Steering by change of balance

For steering strictly so called, a bird trusts much more to change of balance than to the use of the tail as a rudder. If he wishes to direct his course to the left, he flings himself onto his left side, his left wing pointing downward and his right wing upward[1] (fig. 83, p. 149). His wings held thus prevent him from moving onward in the old direction, and, once more availing himself of the parallelogram of forces, he advances along the path of least resistance, the direction in which his head points. As a skater wishing to go to the left throws his weight on that side, and so causes his skate to describe a curve in that direction, so the bird flings himself on his side and describes a most splendid curve. It is a grand thing to stand on the top of a cliff—on the Bass Rock, for instance—and see the gannets wheeling and wheeling with outstretched wings. Often the wind blowing against the cliff forms an up-current and enables them to rise and then sail along with a very slight downward incline without ever a beat of their wings. A good six feet their wings stretch from tip to tip, and standing not far above, and watching them through a good field-glass as they gyrate, one ought to be able to discover

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[1] *Vice versâ*, if steering to the right.

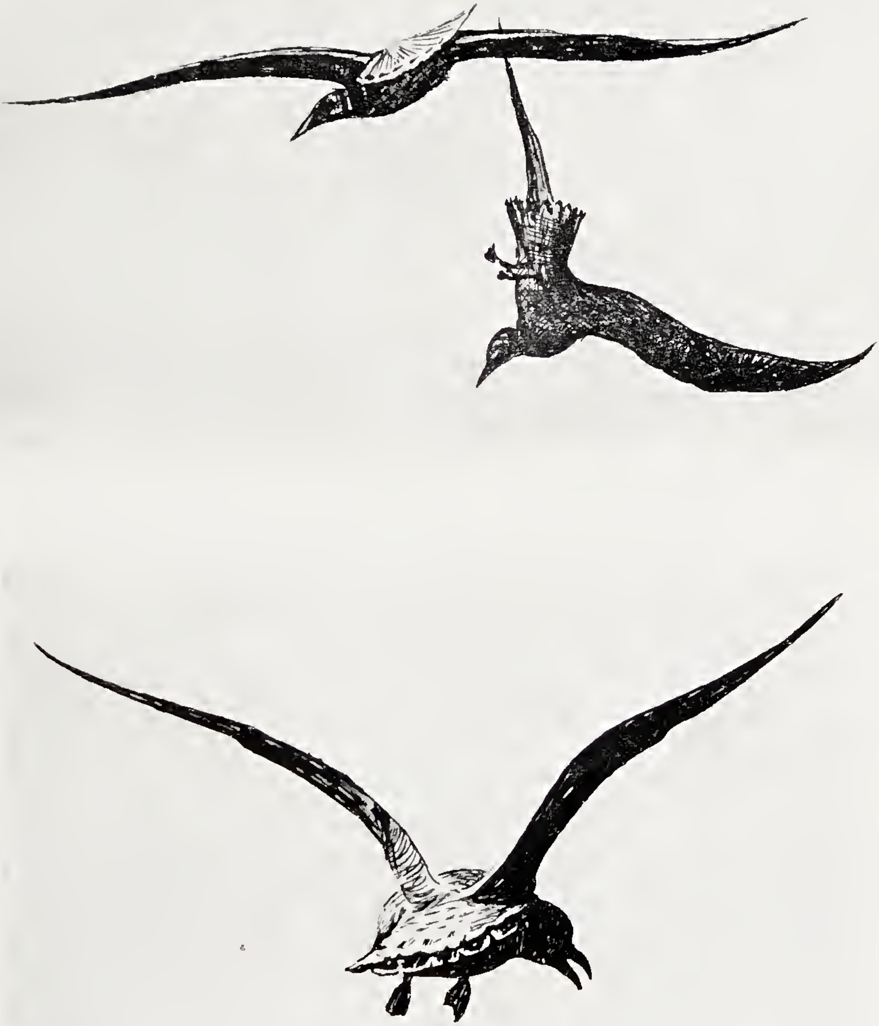

FIG. 82.—Gulls, showing method of using tail. Drawn from photographs.

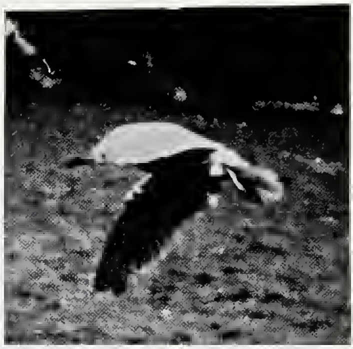

Fig. 83 (1).—Black-headed Gull steering to the right by throwing itself onto its right side.

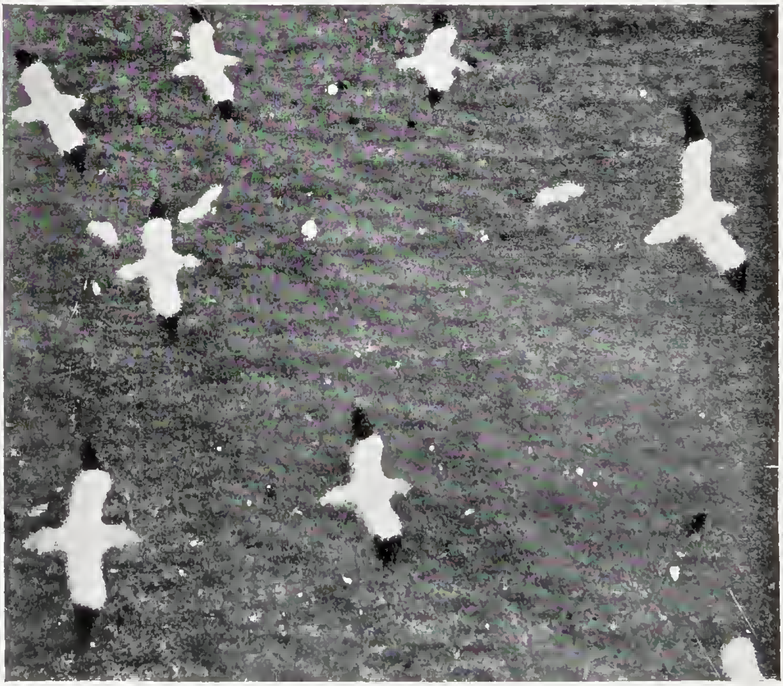

Fig. 83 (2).—Gannets steering by change of balance.

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by what means they perform their wonderful evolutions. And yet, after staring at them for hours, I have not been able to get really good evidence of their methods. Very possibly what happens is this: Wishing to go to the left, they bend at the waist, bringing head and tail on this side slightly towards one another. (All birds have some flexibility just at the waist, and those that are best at steering have, according to my observations, more than others.) The result of this, I believe, is that the centre of gravity is moved slightly towards the left, and so there is less supporting power on the left side of it than on the right. Consequently the bird rolls over on that side, his left wing pointing down and his right wing upward (fig. 83, p. 149). I think I have seen this bend at the waist take place when gannets are wheeling to one side or the other, but I should not like to say on oath that I have seen it; the feathers make it so difficult to see how the body beneath them is moving. We may lay it down that if the bird wishes to roll over on one side or the other, only three alternatives are open to him. He may shorten his wing on one side. This might be effected by partly flexing it, but I believe it is done by shifting the centre of gravity by means of a bend at the waist. This amounts practically to a shortening of the wing on that side. Another means is to strike harder with one wing than the other—with the right wing if a turn is to be made towards the left. How easy it would be for a bird to do this! His wings can move independently, for gulls when washing will often raise one while keeping the other flexed. But is this done during flight? In a turn to the left the right wing is raised, and this hardly looks as if there were a harder stroke on that side. And when gannets or gulls are wheeling, or vultures (for I have watched them also at close quarters), both wings are held, as far as can be seen, perfectly rigid and motionless, the line of each continuing the line of the other, so that the bird forms a cross. There is no sign of a wing-beat, no sign of a shortening of either wing by means of a partial flexing. I strongly suspect that there is a bend at the waist such as I have described. A third means of altering the balance has been pointed out to me by Mr J. A. Tregelles.

Holding the wings so that they form a rigid rod from tip to tip, the bird may pull the body towards one side or the other. This would be very effective, and may very well be the method birds actually employ. I have compared the bird to a skater, but the analogy of the skater swerving to right or left merely by throwing his weight on one side or the other might be misleading. Really the skater kicks against the ice, as he finds to his cost if his skates are very blunt. In that case, instead of describing a beautiful curve, his feet may possibly fly from under him, and he may lie prostrate. The bird, if he wishes to describe his graceful curve, must either kick off from the air or else shorten sail on one side, the probable method of effecting which is the bend at the waist; or he may, as I have said, pull his body to left or right while his two wings are in the same straight line, forming a rigid rod. But though I incline to the belief that either the second or third method is the one actually adopted, it may no doubt be a very slight wing movement that is extremely hard to detect. When gulls are following a steamer, keeping pace with her by the help of favouring air currents without any beating of their wings, they are busy all the time balancing, making slight adjustments of their wings to suit the varying gusts. If they do this for balancing purposes, why not use this method when wishing to roll over on one side and to swerve to right or left? We may well say, "Why not?" And yet, when I have watched gannets or other birds wheeling and turning, I have seen no evidence of their using their wings to effect a turn.

Balancing

Equilibrium between left and right

For the man who is ambitious to build a flying-machine and sail through the air the question of balance is a very difficult one. Lilienthal, a German of great enterprise and inventiveness, equipped himself with long wings, and jumping from a slight elevation—a little less than 50 feet—he would sail through the air for some distance, sometimes covering 500 yards before he alighted on terra firma. But at last, skilful as he was, the question of balance proved fatal to him. A sudden gust struck him, and a man of fine spirit and enterprise was no more. Mr

Pilcher, a disciple of Lilienthal's, met with his death from the same cause. These two aeronauts did not, strictly speaking, fly, but only sailed through the air. Their "wings" were fixed, and Mr Pilcher intended, I believe, when he had grown familiar with the gusts and flaws of the wind, to get motive power from a small engine. I mention these two aeronauts just now only to show how important to those that trust themselves to the breezes, whether men or birds, is the question of balance. I have already spoken of the gulls that follow steamers, seeming to hang motionless in mid-air over the stern. But if you watch them carefully you will see that though there are no wing-beats for purposes of propulsion, yet there are perpetual little shifts of the wing in order to maintain equilibrium. As each capricious gust strikes them they have to make nice adjustments if they are to avoid a fiasco. No doubt the gull is helped by the fact that the pair of strong muscles that lower the wings and which account for nearly one-fifth of his whole weight are situated on the lowest part of him, on the breastbone. But the fact that the centre of gravity is low down does not relieve him of the necessity of showing skill and resource. Hence the continual very slight movements of his wings, often, I think, independent movements of the right or left wing, not comparable at all to the powerful strokes of flight, but sufficient to sway him this way or that.

The incline from head to tail and its regulation

Not only must a bird keep himself evenly poised by preventing the right or left side from dropping. He must also be able to alter his incline from head to tail, and that at a moment's notice. If he wishes to descend he must bring it about that his head is the lowermost part of him, while his tail is in air. If he wishes to ascend rapidly he must put his body at a steep incline. If he wishes to stop suddenly, he must cause his whole under-surface, body, wings, and tail to meet the air. All these things he succeeds in admirably.

There is a broad sheet of muscle, called the *latissimus dorsi*, that, springing from the backbone (from just behind the neck even to the pelvis sometimes—a very broad sheet), attaches its further end to the humerus or upper-arm bone. When the wing descends in flight the *latissimus* contracts and hauls upon the body of the bird, raising the hind-quarters. The scapula or shoulder-blade also plays a part in this.[1] When the wing descends (the muscle so pulling it that the front edge takes the lead and the humerus or upper-arm bone is rotated or twisted round), the result is that the scapula is given a more upward slope than it has when the bird is at rest. The long thin scapula (fig. 49, p. 104) is attached to the ribs by muscles, and its hinder part rising lifts the ribs and with them the backbone when the wing beats downward. Take a dead bird and move the wing, keeping the front edge down, and you will at once see how it tends to raise the hinder part of the body. How important this work of the *latissimus* and of the scapula with its associated muscles is, you may realise if you think of a man with wings instead of arms, but otherwise with the normal human anatomy. When he flew (imagine the impossible), his body would hang down between his wings as a candle hangs by its wick. A bird if he wishes to descend has only to contract the *latissimus* and so jerk his hinder quarters upward, and he is at once in the proper attitude, head downward.

The tail plays an important part, relieving the muscles of some of their work. If a bird, when he has plenty of way on, spreads his tail and gives it a downward slope, obviously this will help to tilt his hind-quarters up and his head down. It is interesting to watch a small bird perched on a bare bough, with a strong breeze blowing in his face. He has constantly to be lowering and raising his tail in order to maintain his equilibrium. Watch a lark rising against the wind. The tail has plenty of work to do.

The frequent spreading and narrowing of the tail during the rapid evolutions of flight, such as are practised, for instance, by peewits when they think you unwarrantably near their nest, or by swallows or swifts, have to do with the sudden checking of speed and with balancing.

Alighting

The difficulty of alighting is no slight one, as every one who has considered the question of flying-machines knows. You don't want to have the whole framework shattered (and perhaps

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[1] The scapula helps a little only. See p. 155.

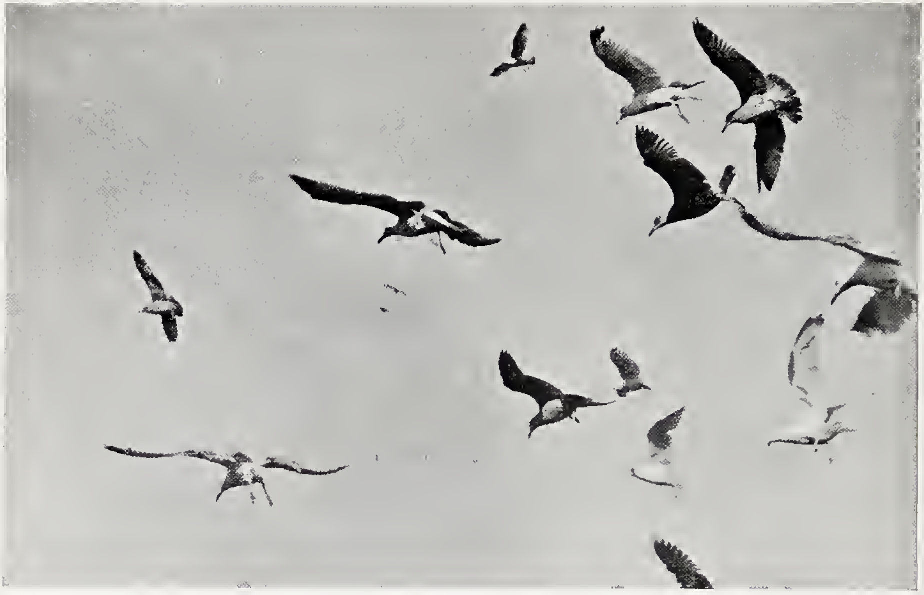

FIG. 84.—Gulls hanging their feet down on nearing the place of alighting. One towards the right shows gaps between the tips of the flight-feathers. Bastard wing conspicuous.

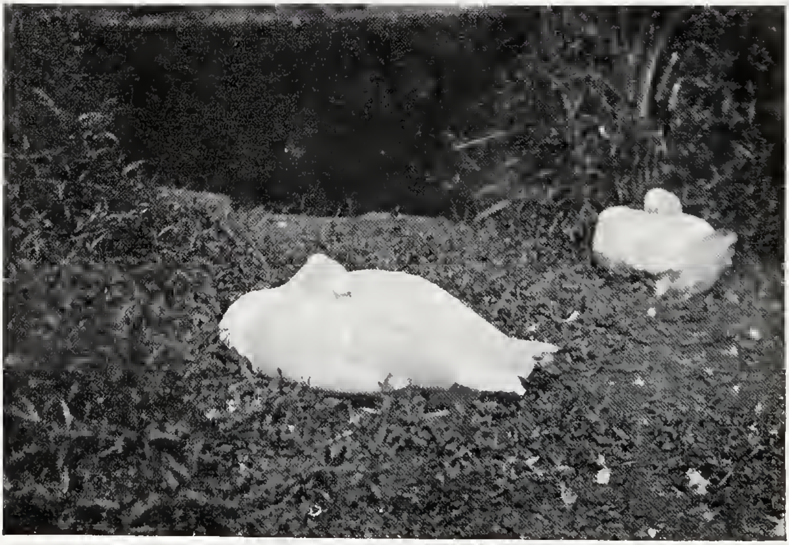

FIG. 85.—Swan. When a bird is lying thus, its weight preventing the breast bone from moving, the hinder part of its back rises and falls with the process of breathing.

yourself into the bargain). Birds have solved this problem that so perplexes the human aeronaut. If, when flying at high speed, a pigeon wishes suddenly to stop, he has only to relax the *latissimus* muscle, so that his body hangs vertically, then spreading tail and wings to their full extent (the pigeon when alighting spreads even the little bastard wing[1] in order that no half-inch of canvas may be unemployed), he presents a large flat expanse to the air, his progress is suddenly arrested, and he alights like the herald Mercury without shock or jar, and folds his wings, to all appearance, with a sense of satisfaction. If the spreading of the wings is not enough to stop him in his rapid descent, he will give a stroke of his wings while his body is nearly erect, "backwater" in fact, and so prevent any jar. Gulls and gannets alight less gracefully, hanging down their feet and paddling with them in ungainly style when they near their destination (fig. 84, p. 153). A falcon when he makes his swoop descends like a thunderbolt, and though his victim may be flying not very far from the ground —a pigeon, for instance, on which a tirzell is being practised—yet he checks himself easily and alights without mishap. M. Mouillard,[2] whose remarks on the flight of birds are always of interest, thinks the waders require their enormous wing surface solely to save their long legs when they alight. Mr Maxim's flying-machine descended to earth with such disastrous results that it lay on the ground *hors de combat*.

Breathing during Flight

Nothing is easier than to mistake our familiarity with a fact for a real understanding of it. Of course birds must breathe during flight, since they remain a long time on the wing. So familiar is this obvious fact that the process seems to require no explanation. And yet the physiologist John Hunter realised the difficulty of it so thoroughly that he suggested that birds did not inhale and exhale when on the wing, but made use of the air stored in their capacious air-sacs when they started on their flight! Here is a strange theory for a really great physiologist to have to own as his own child! It is true the air-sacs into which the lungs open are ample and roomy, in particular the abdominal sacs which lie between the backbone and the intestines. But when we consider how many cubic feet of air are considered necessary for a child at a Board School, a child who sits comparatively torpid, how can we expect a crane during the long hours of a migratory flight to be content with a cubic inch or two.

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[1] Also during flight. See fig. 78, p. 145.

[2] *L'empire de l'air*, p. 84.

Immobility of the breastbone during flight

The movement of the back

In the process of breathing with which we are familiar, a vacuum is made by the drawing down of the diaphragm. In rapid breathing the ribs and chest are raised a great deal. Now, the bird has no organ corresponding in function to the diaphragm of mammals. Moreover, during flight it cannot move its breastbone. The wings require a firm pivot on which to turn, and this pivot is formed by two bones, the merrythought and the coracoid, which are firmly fastened to the breastbone (fig. 49, p. 104).[1] The shifting of the pivot owing to breathing would make flight very difficult. As a matter of fact the pressure from the wings, at any rate during the down-stroke, is such that the breastbone is held firm. A chicken is in a similar difficulty when it sleeps with all its weight resting on the keel of its breastbone. A Chinese goose that I once watched at the Zoo as he lay on his breast uttering his uncouth cries suggested to me the solution of this problem. The hinder part of his back rose visibly with the process of breathing, and since there was no weight upon the legs there was nothing so very wonderful about this. If any big bird be watched when lying on his breast this phenomenon may be seen (fig. 85, p. 153). When a bird is standing, the weight upon the legs makes "back-breathing" impossible. But for our Chinese goose lying on his chest, or for a sleeping hen throwing all her weight on the breastbone, there is no reason why the back should not rise and fall with inhalation and exhalation. I once suspended a freshly killed pigeon by its wings, and by means of a tube inserted into the windpipe inflated the air-sacs. The backbone a little in front of the thigh joint lifted rather more than half an inch, while the movement of the breastbone was inappreciable. Here the pressure or rather the pull at the shoulder joints was uniform and continuous, whereas during flight the pressure during the down-stroke is much greater than during the up-stroke. Still, the pressure is never entirely taken off. The fact is that, when the muscles that are called the external intercostals straighten the ribs, the result must be that either the breastbone or the back must move according as the one or the other yields the more easily. And during flight the back is that one. For not only do the intercostals strive to push it up, but other muscles haul at it from above. The *latissimus dorsi* that passes from the backbone to the humerus or upper-arm bone, raises the hinder quarters during the down-stroke. Moreover, the upward slope given to the scapula or shoulder-blade,[1] also during the down-stroke, stretches the muscles that connect it with the ribs, and so tends to raise the roof of the cage in the top part of which lie the great air-sacs. The raising of the roof must cause a vacuum, as you will see if you take a forceps and hold a dead bird by the backbone: the weight of the intestines will straighten the ribs and allow the air-sacs room to expand. One point further: the backbone has a great deal of freedom of up-and-down movement at the waist. So that, to sum up, we have ocular evidence that birds do breathe by movement of the back when they are lying on their breasts, and we have all the machinery for breathing by this method during flight; whereas chest breathing is rendered difficult or impossible by the pressure of the wings, and would, moreover (should it actually take place in spite of hindrances), render flight precarious by making the pivot, on which the wings turn, shifty and unsteady.

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[1] Also fig. 48, p. 103.

Wind and Flight

Rising against the wind

Anyone who has gone in pursuit of snipe knows their habit of rising against the wind. Not so many people (since there is nothing practical to be gained by it) have noticed that larks always face the wind when they rise, though they will mount to a great height when there is hardly a breath stirring. Big heavy sea-birds, such as the cormorant and the gannet, always like to feel the wind in their faces as they lift themselves heavily from the water.[2] A cormorant will sometimes fly a considerable stretch away from his destination, and all for the advantage of having the wind right ahead to help him to heave his ponderous weight a few feet above the water. Generally it is hard to say what a bird's motive is for any particular action. But here we may feel fairly positive. Suppose that a number of cormorants have been fishing together. All but one have left the fishing ground and are sociably grouped, gorged and torpid, on a neighbouring rock drying their wings. One belated member of the party is left fishing. At length he determines to join his fellows. But he does not make straight for the rock. He flies in the opposite direction, with the result that the wind blows in his face as he rises. Having attained a slight but sufficient altitude he turns and flies to the rock. Off the coast of Sutherlandshire I once saw an admirable example of this. In such a case we can hardly be wrong in deciding that the opposing wind helped him so much that it paid to fly the extra distance.

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[1] During flight pressure prevents the scapula from moving *much*—experiment with a dead bird shows this. The breastbone connected with the scapula must also move *a little*. The raising of the hinder quarters is mainly due to muscles, especially the *latissimus*.

[2] Little birds rise more easily. See note at end of chapter.

Many people have seen no need to explain how the wind helps the cormorant and the snipe. "Of course the wind must lift the bird." The "of course" is not so obvious. A kite is lifted by the wind—until the string breaks, when down it comes, even though the break is near the kite, so that it is relieved of all the weight of the string. Even if the kite by some means were kept in the right position facing the wind, still, none the less, down it would come. When, some way back, I compared a bird rising by his own effort to a kite, I insisted on one point above all, viz. that there must be something corresponding to the string, and that this something was the bird's own momentum. Now, if the wind helps him, it must somehow be what the string is to the kite. If the bird has to make a string entirely by means of his own momentum, he is not assisted at all. This is, then, what we have to discover: does the bird in any way get momentum, when he faces the wind, apart from his own effort? Or (what would do equally well) does he, like the kite held by a string, resist the breeze, not being made its plaything, but refusing to move save in one direction? If, in fact, he has inertia, *i.e.* is not carried like a balloon before the wind, but resists like a thing lying on the ground, then the wind will tend to lift him. This inertia the wind does give him, and therefore it is that he makes a point of heading towards the wind when he rises.

Velocity of wind increases with altitude

Some experiments made some years back by Mr R. C. Gilson and his brother and myself brought out a characteristic of wind which to the bird is most important. Its velocity increases steadily with altitude. Close to the ground it has little force, though at the level of a man's head there is a stiff breeze. Does not a sailor stoop and light his pipe close to the ground? And I have seen gulls flying against a blizzard with their wings almost touching the sand. A few feet higher up they would not have been able to face the fury of the blast. Well when we measured the pace of the wind with an anemometer we found that the increase with altitude was rapid. The following figures are averages from four series of experiments:—

Altitude.	Velocity of wind per minute.
2 inches	515 feet
1 foot	736½ ,,
2 feet	770 ,,
4 feet	918 ,,
7 feet 6 inches	1021 ,,

The following are averages from two series of experiments:—

Altitude.	Velocity of wind per minute.
7 feet 6 inches	1375 feet
9 feet 6 inches	1457½ ,,

We then attached a kite to a spring balance and measured the pull at different altitudes. The pull increased up to a height of 420 feet: at 204 feet it was 18 lb.; at 420 feet, 25 lb. The altitude was measured by means of a sextant. I have also tried the experiment of letting fly simultaneously a number of small balloons inflated with hydrogen gas. Some were more distended with gas than others, and consequently rose higher, some to a height of 500 feet or more. The higher ones decidedly outpaced the lower ones. Far more elaborate experiments with anemometers suspended on kite wires have been recorded (*Nature*, April 22, 1886), and these showed that there is an increase in velocity up to 1100 feet above the ground. Still the rate of increase was very slight above an altitude of 549 feet. But to return to our experiments at low levels. A bird has at his disposal a difference in velocity of nearly 300 feet per minute between the altitudes of 1 foot and 7 feet 6, and this in quite a moderate breeze, blowing at the higher level, only a little over 11½ miles in an hour. To show how the bird makes use of this, let us for the sake of clearness divide the air into imaginary layers and consider what will happen as he passes from a lower to a higher one. We know that as long as he has inertia, as long as he resists the wind like a kite, and is not carried by it balloon-like, he will be lifted. Now, as he rises from stratum to stratum, he has inertia in each, since, horizontally, he moves at the rate of the slower stratum below. Resisting the wind, he is bound to be lifted by it as a kite is lifted. Hence a lark, even when he has already attained an altitude of 500 feet or more, still continues to face the wind. The gain, owing to the very gradual increase of velocity at such altitudes, may seem too small to be worth considering, but it must be remembered that if he rose facing *with* the wind, there would be positive loss. The wind beating upon his back would drive him downwards. When a piece of cardboard, as I showed above, is flung horizontally, but with an upward slope from the front to the back edge, the action of the air makes it plunge down to the ground. In the same way the wind acting on the back of a bird will tend to force him downwards. Many observers have noticed that birds never fly with a very strong wind directly behind them. The explanation is, I believe, as follows. Supposing the bird travels at the rate of 50 miles per hour and the wind at the same pace, then he would get no support from his velocity, because it is shared by the wind. He is part of the moving tide. And there will be no current of air to lift his wings after a down-stroke, so that the work will have to be done entirely by muscles. But if he could manage, however rapid the wind, to fly at a considerably greater pace, this difficulty would be got over. This, however, would be no easy matter, at any rate at the start. If, facing with the wind, he tries to rise from the more slow-moving currents below

Flight with the wind

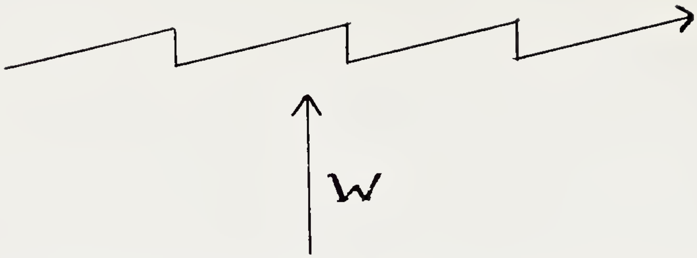

FIG. 86.—Diagram illustrating flight at right angles to the wind, without movement of the wings. The zigzag line represents the bird's line of flight ; W, the wind.

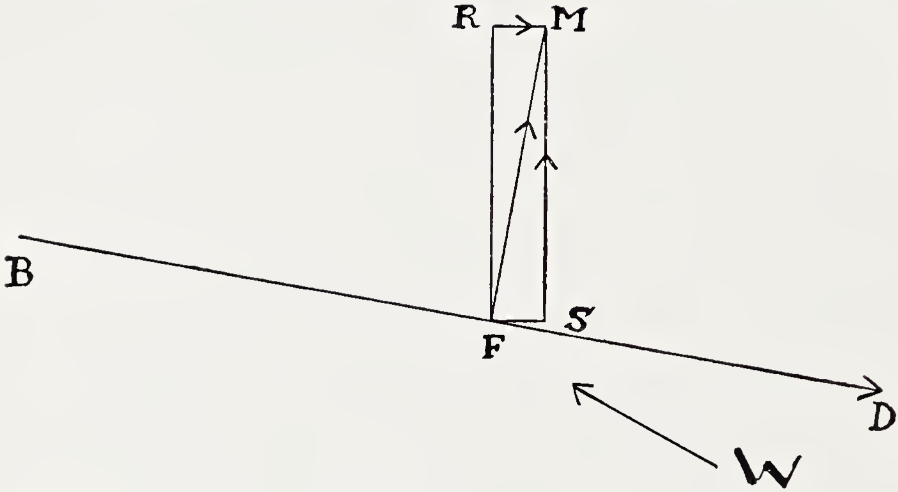

FIG. 87.—To illustrate advance without wing beats in the teeth of the wind. W, the wind having an upward incline ; BD, the body of the bird, having a downward slope. Since the wind inclines up, the bird's own weight gives him inertia in relation to it, and the force of the wind (FM) is resolved into two (SM and RM).

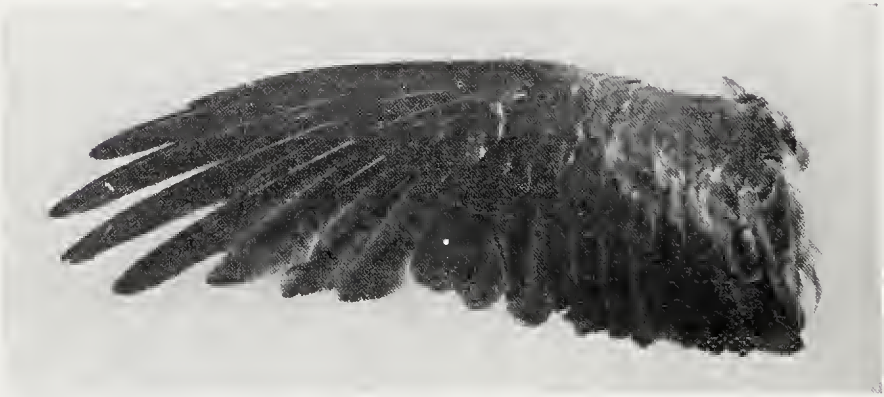

FIG. 88.—Wing of Red Kite, the feathers spreading as they do during soaring. One-sixth actual length.

Facing p. 159

into the gale high aloft, a rush of air will impinge upon his back and force him downward, will moreover disarrange all his neat plumage. If (the other alternative) he faces the gale, he will not be his own master, but the sport and plaything of the wind. Even if we imagine him well on his way and able to outpace the wind, still probably the eddies and gusts in what even a sailor would call a stiff breeze are difficult, or, at any rate, unpleasant to cope with. A moderate breeze is a different thing altogether. Coming from directly behind him, it helps the bird on his way, and the best times are made by homing pigeons when there is a tail wind blowing.

Flight at right angles to the wind

It is a fine thing to get assistance from the wind.

It is a far grander feat when the wind is made to do all the work and the bird advances, and at a good pace too, without a single beat of his wings, merely turning to account the superiority in velocity of the higher currents to the lower. Suppose that a fairly strong breeze is blowing, and that a gull wishes to travel at right angles to it. Having first attained some elevation —30 or 40 feet say—he then descends at a good pace down a gentle incline, at right angles to the wind. When near to the ground or water, he suddenly turns and faces the wind, which, owing to the increase of its velocity with altitude, lifts him to his former level, whereupon he again slides down his gentle incline, and at the bottom once more turns and faces the wind, and so *ad infinitum* if all the conditions are favourable (fig. 86, p. 159). If the wind is not as strong as he requires it, he will have to put in a few strokes occasionally, and generally he will be reduced to this at intervals. But sometimes he will travel a long way thus without a stroke. Gulls will often follow a steamer, keeping a little to one side, in this style. I have seen them also on land practising this performance.

Another method

Gulls have another method of making the wind carry them when it is blowing at right angles to the direction in which their destination lies. This method depends on the wind's having an upward incline. Suppose, for instance, that a gull wishes to return home in the evening from the west coast of the Isle of Man to the Calf Island which lies to the south. The wind is blowing from the west, and as it strikes the cliffs of course gets an upward incline. The gulls face the wind in order to get all the supporting power of the up-current—they face west, that is. There they hang suspended high in air, as one may see a kestrel poised, his wings quite motionless, when the incline and the strength of the wind are such as enable him to balance. He spreads all sail; even the little bastard wing is extended so that daylight can be seen between it and the wing proper. So vultures, too, may be seen poising themselves in air. The body is horizontal or nearly so, otherwise the bird would be forced backward. As it is, they, the kestrel and the vulture, hang motionless. But the gull does more than this. He not only poises himself upon an upward wind, but all the time that he hangs in air he is travelling towards his destination. In this case he faces the west wind and floats southward toward his night quarters. Thus he travels with the left wing leading. There must be a slight shifting of the centre of gravity towards the left side, so that he descends a gentle incline in that direction. Some loss of elevation seems to be inevitable, but it is often difficult to detect, so slight is it. When the wind blows nearly at right angles to the course of a steamer, being deflected upward as it strikes against the vessel, gulls often make use of this method, and so keep pace with her without much expenditure of force. Sometimes there is a slight variation. The line of the wings is not quite in a line with the bird's course, but makes a slight angle with it, so that, the vessel travelling due south, the leading wing points S.S.E., and the gull's head W.S.W., the angle varying as the breeze requires. The essential thing is that the bird should face the wind—the wind, of course, having an upward incline.

Advance in the teeth of the wind

Under certain conditions a gull is able to advance in the teeth of the wind with wings outstretched, motionless except for very slight movements for purposes of balancing. The sight of this marvellous performance often relieves the tedium of a sea voyage. The gull hovers over the stern of the vessel and seems suspended motionless in the air. Really all the while he is keeping pace with the steamer. On first thoughts this seems almost uncanny, and makes one half inclined to agree with Herr Gätke that birds have a special dispensation enabling them to laugh at ordinary physical laws. We may think this for a moment. We then, if we are sensible people, set to work to find the answer to the riddle if we can. Often if the gull as he hovers over the stern is closely watched, it can be made out that he is not always at the same level. For some time he will descend down a very gentle but perceptible slope. Then setting his body a little differently, giving it a slight upward incline from tail to head, he will gain altitude and at the same time lose ground, *i.e.* not keep pace with the steamer. Having attained the required altitude, he will again descend.

We might think that in this alternate ascent and descent we had the clue to the problem. But not unfrequently the gull will continue for a long while without losing elevation, will even advance at a smart pace, rising all the while. Sometimes, it is true, things go wrong, and it is an imperfect performance interspersed with beats of the wing. But if the conditions are really favourable, a gull will sometimes travel a mile without one half stroke, for long spells maintaining a uniform level without any alternation of ascent or descent. And it is said that the albatross is more clever even than the gull in making the wind carry him. What, then, are the necessary conditions? There must be a strong breeze blowing, and it must be a head wind, or better, I believe, some few points off that, sweeping over the vessel from a point near the bows. Striking against the vessel the wind gets tilted upward, and it is this strong up-current that enables the gull to carry out this wonderful system of progression. That the wind has an upward incline, does not admit of dispute. When it strikes the vessel, or rather just before it strikes, it must be deflected upward. I have verified the fact by letting fly small pieces of paper and by flying a handkerchief from the end of a stick. Given this upward current, the gull's progress, wonderful as it is, becomes intelligible. The bird sets his body so that the general incline, if we include the whole expanse (the tail and the back margins of the wings must not be neglected), is slightly downward from tail to head. The wind will act at right angles to the bird's surface and so propel it as the diagram (fig. 87, p. 159) will show.

The forward slope of the line FM shows that the wind is not only supporting the bird but driving it forward. As a fact, of course, the bird's surface is not all in one plane. The impact of the wind on some parts will, so far from propelling the bird, even tend to drive it backwards. On other parts the impact will tend mainly to propel, notably on the back margin of the wing, where the force of the wind will cause the feathers to bend so that there is an upward incline from front to back. But if BD truly represents the *predominant* incline, there must be forward movement. There must be, it follows inevitably. Yet how marvellous is the skill of the gull and the albatross, who can utilise every peculiarity of the wind and adjust themselves to every gust and eddy! But gulls and albatrosses are not the only birds who show this astonishing dexterity. In Algeria I saw two eagles advance a mile and a half (as nearly as I could estimate the distance) without a motion of their wings, the wind being right ahead. Having achieved this once, they flew back with the wind, propelling themselves with their wings in the normal way, then again sailed majestically back without a suspicion of a wing-beat. The first time they seemed to maintain their level without either loss or gain of elevation. The second time they were so high in air that it was impossible to have any very definite opinion as to whether they were keeping the horizontal exactly. Undoubtedly the wind had an upward incline, having been deflected by a mountain ridge. Even my handkerchief tied to my umbrella detected the upward slope. The eagle's method is the same as that of the gull and the albatross.

Use of a very local up-current

There is yet another strange mode of progression that I have seen gulls practising in the wake of steamers, making use of strong up and down currents that the vessel causes in its passage through the air. Of course behind the stern there is a great down-draught of air to fill the space just vacated by the vessel. A scrippet of paper let fly from the stern descends at a furious pace, but having almost touched the water at a little distance behind the ship, it is caught in a strong up-draught and whirled aloft. The down-draught at the stern strikes the water and, rebounding, forms an up-draught. Here is a fine chance for a gull, at any rate if the wind blows from ahead, so that there is no disturbing cross current. Let us imagine the gull beginning operations by flying low down over the sea in the ordinary fashion, beating the air with his wings, till he finds himself suddenly in the up-draught a little way behind the stern of the steamer. He is lifted like a leaf to the level of the deck or higher. Altering his pose, he then descends, making much headway at the same time, with body sloping downward and wings outstretched. When he puts himself thus, head downwards, apparently the up-draught does not hinder his descent, and his downward-forward swoop carries him onward till he is near the stern of the steamer, beyond the region of the up-draught. His pace now slackens, but the steamer moves on with uniform speed. Consequently the up-draught (or the region of the up-draught), moving with the steamer, overtakes him. He is again whirled aloft and again descends. It is a wild performance. At its best it is accomplished without any interspersed wing-beats, the outspread wings only moving now and then very slightly for the purpose of balancing. And while you watch the process, this tobogganing with an up-slide as easy as the down-slide (no toiling uphill with a toboggan), you cannot help feeling that the gull takes a keen pleasure in the movement and in the exercise of his skill. He is there not only to pick up a morsel of biscuit thrown him by a passenger or a bit of potato peel or a shred of meat from the cook, but he is there also to enjoy this wonderful up-current (no doubt associated in his mind with potatoes and biscuits and scraps) that enables him to practise an exhilarating and weird kind of locomotion.

Soaring

The eagle, the king of birds, soars to a great height, till he looks hardly more than a speck, choosing by preference bright days. If he is watched through a good field-glass, it will be seen that his wings form a rigid rod, with the great primary feathers separated and looking like so many fingers. In this attitude he circles round, in an ascending spiral, till he is as high up as he wishes to be, or till the wind is no longer of the kind required. There is not a suspicion of a wing-beat, there is no stroke, as some observers have maintained, with the great wing feathers. He is not lifted by muscular effort, but he is skilfully using the air currents, of whatever nature they may be, making them raise his ponderous bulk (no less than eleven and a half pounds in the case of a Spanish Imperial eagle that I weighed). Getting the wind to do the hard work, he has only to hold his wings rigid, each wing continuing the line of the other, and to feel the pulse of the breeze, swaying and turning so as to make the most of every ascending current, or every irregularity in horizontal velocity. So practised is he in the art, that there is, we may well believe, no strain and no effort. But the notion that these great soarers sleep as they circle round is ridiculous. No beast or bird who wishes to sleep would choose such a chartered libertine as the wind for a bed. No! Soaring is a great feat of skill, demanding perfection of nerve. From the muscles it is only demanded that they shall hold the wings rigid. It is wonderful that no ache or stiffness results from this; but the bird's muscles seem adapted to such prolonged strains. When he sleeps upon a bough, the bending of the ankle joint of itself contracts the muscles that bend the toes, and so prevents him from falling. The strain on these muscles continues throughout the time of sleep. But when the first glimmer of the sun appears, the bird awakes with every fibre refreshed, and ready for the labours of the day.

Separation of the great flight feathers

Before we go on to the main and very difficult problem of soaring, let us consider why it is that the great remiges, the primary wing-feathers, are held apart, so that the air passes between them (fig. 88, p. 159). Certainly the birds that propel themselves best with a powerful wing stroke, *e.g.* the swift and the gannet, have narrow wings that slope to a point, the edges trim and neat, and the feathers overlapping nearly to the tips, so that they are impervious to air. For a soaring bird, I believe there is a gain in steadiness from the spreading of the wing feathers till there are wide gaps between their further extremities. Mr Pilcher's wings, each a great spread of canvas, yards long, had a number of small round holes in them. I was astonished when I noticed this, but he told me they were much steadier when thus perforated. When wings are impervious to the breeze the air collects and eddies under them, then, through some slight swaying movement, escapes all at once at one margin, causing for the moment, perhaps, a complete loss of balance. The gaps between the great feathers, I think, probably play the same part as the holes in Mr Pilcher's wings. They prevent sudden, ungovernable rushes of air. True, the gull's wing is rather pointed, and he, as we know, is an expert in the use of wind-currents. Even as a soarer he is well up in the second class. Still, his wing is not of the true pointed type, like the gannet's or the swift's. There are gaps between his primary feathers and between his secondaries; though not so deep and broad as in the kite (fig. 84, p. 153).

Soaring with the help of an up-current

When we see one of the grand soarers describing his ascending spirals in the air, our first thought is that there must be an up-current to help him. Without that it would be impossible, so we cannot help thinking, unless, indeed, the bird has some way of making himself a balloon. Can it be that, taking a great deal of air into his capacious air-sacs and making it lighter by raising it there to his own high temperature—high enough to mean high fever in a man—he so reduces his specific gravity that he rises, balloon-like, in the air? A moment's reflection is the death of this balloon theory. The difference in weight between a few cubic inches of hot air and the same amount of cold air is not to be measured in common scales, and a Spanish Imperial eagle has a weight of eleven and a half pounds to heft.

But the idea of up-currents is worth considering. It may be the explanation of all soaring. Certainly it explains it in many cases.

Herr Lilienthal, whose bold attempts to navigate the air, ending in a fatal fall, I have already recounted, had the strange idea that the normal direction of the wind is upward, at an angle of from three to four degrees to the horizon. This is an odd picture—the earth's envelope of air in defiance of gravitation going skywards, in spite of the undeniable fact that there always is air upon the earth's surface, in truth a pressure of nearly fifteen pounds to the square inch! At New Romney, some years back, in order to investigate the facts of upward and downward currents, I had made for me a vane that worked vertically up and down. An iron tripod carried two iron uprights. The horizontal rod that bore the vane (like a weathercock laid on its side) passed through round holes in these uprights and turned easily. The larger arm, the vane, consisted of a piece of thin deal one foot long by six inches broad, attached to a light iron rod, and was exactly balanced by a lump of lead attached to the shorter arm. With this apparatus I experimented on the currents of air above or on either side of such small barriers as banks of a few feet high. The great flat expanses at Littlestone and New Romney were admirably fitted for such work. "Standing on a bank only two feet high, its iron tripod lifting it four feet above the bank, the vane pointed decidedly upwards. Twelve yards to windward of a bank rising only six feet above the level, the vane was not quite steady, but on the whole horizontal. At a distance of six yards there were occasional upward swings; at four yards' distance there was a decided upward tendency, and this though the bank itself presented only a very gentle incline." Now for the leeward side. "Five yards to leeward of a bank six feet high it indicated that the wind blew downwards, making a large angle with the horizon; there was but rarely an upward gust. Ten yards from the bank the direction was still mainly downward, but with not unfrequent upward movements. At twenty or thirty yards' distance from the bank the wind came in wild gusts as often upward as downward."[1] A barrier, then, be it bank or cliff or hill, deflects the wind and gives it an upward tilt. On the further side its incline is downward. In its upward course, when it overtops the barrier, it strikes against horizontal currents and by them is deflected downward, so that a little way further on there is a strong downward flow of air, though to leeward of the bank at New Romney it came in irregular gusts. Substitute mountain ridges, as long as they are not very broad, for an insignificant bank, and we have the same phenomenon on a larger scale. When the wind blows straight at a hillside, its course, as you find if your hat blows off, is upward. But what happens on the other side is not familiar to every one. When I was staying at Biskra, the southernmost point in Algeria reached by the railway, lying just on the northern margin of the Sahara, there was one day a very high wind, driving the sand before it with such force that if one faced it one's eyes were nearly cut out. A few miles off are some hills, rising some 1000 feet. The tops of these stood out clear above the sweeping sand, and seemed the only place where a walk would be tolerable. A tramway took me to the foot. The wind blew straight against the ridge, and was, of course, deflected upward. On getting to the top and looking down on the other side of the narrow ridge, I was surprised to find that the tall wiry grass growing at the bottom, on the leeward side, where I expected to find a region of calm, was swaying wildly to and fro in the wind. Descending a little way, and letting my handkerchief fly out as a vane, I found there was a down-current, varied with occasional up-currents. Thus, even when deflected upward by a high hill ridge, at any rate if it is a narrow one, the wind soon loses its upward slant and exchanges it for a downward one. I noticed the same phenomenon near Gibraltar when the wind blew furiously against a steep hill-face. On the leeward side also was a strong wind, but with a downward incline.

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[1] *Structure and Life of Birds*, p. 238. *Loc. cit.*, p. 238, I have corrected a misprint. Six feet, not eight, was the height of the bank.

Here we have facts that go far to explain soaring in a hilly country. The currents with an upward slant will lift the soaring eagle as they support and sometimes lift the gulls that follow a steamer, hanging, with wings held rigid, over the stern.[1] The object of the circling would seem to be to get into a region where the up-current is strong, for there are down-currents and irregularities, as we know. Some spirals are fiascos, and end in loss of altitude, due to failure of the wind. Can the fiasco ever be due to want of skill in these splendid artists? Their art consists in feeling for every available up-draft and facing it with their bodies inclined at the exact angle required.

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[1] On this theory, if the up-current were uniform, the bird might ascend by a gradual *straight* incline. The eagles described on p. 162 *may* have been ascending thus and not keeping horizontal. A gull (p. 161) sometimes rises in this way.

Once when I was at Bude I saw an up-current used in the very simplest fashion. The wind was blowing hard against a cliff, straight against its face, and, of course, took a steep upward incline. A number of gulls accordingly amused themselves by flying repeatedly to its base, whence they were lifted like so many dry leaves to the top. Then, flying a few yards out to sea, they again made for the base of the cliff and were again lifted. Gulls, as far as I have observed, do not soar to a great height, but they are very fond of circling in the air, rising in spirals, as the other soarers do. Now this always takes place over a cliff when the wind is blowing against it, or, if inland, over hilly ground. In Britain there is little soaring to be seen except in hilly country. There are eagles, very rare birds with us, and ravens, both found among the hills. Choughs I have seen circling like gulls over cliffs in Ireland and the Isle of Man.

The question of soaring in a horizontal wind

It is a question whether soaring ever takes place when the wind is horizontal. I believe it is theoretically possible, if the wind is only irregular. It will be best, first, to describe soaring as it takes place over wide-stretching plains where there are no hills near at hand to give the wind a convenient up-tilt. Mr S. E. Peal,[1] an excellent observer, has spent hours in watching through a telescope the great birds—pelicans, vultures, storks, adjutants—that rise in majestic spirals, their wings and body forming a rigid cross, over the great plain of Upper Assam. This plain presents a dead level, 200 miles long, 60 broad. The wind almost always blows either from N.N.E. or from S.W., and generally at about 5 to 10 miles per hour. The birds do not soar when there is a dead calm nor yet in stormy weather. Small tufts of cotton, floating horizontally, pass across the field of the telescope at elevations of from 200 to 2000 feet. The birds rise the first 30 or 60 yards by flapping their wings. Then begins the soaring. As they circle round they descend when going with the wind, then rise when they turn and face it, more than regaining what they have lost in altitude. The momentum of their downward course appears to carry them upward when they turn and face the wind. There is some amount of drift to leeward—Mr Peal estimates it at 10 to 20 feet with each lap.

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[1] See *Nature* for Nov. 4, 1880; Sept. 26, 1889; May 21, 1891.

It has never been my luck to witness soaring so long continued or over so wide-stretching a plain, or with the aid of a powerful telescope. Still I have seen soaring on a grand scale near the mouth of the Guadalquivir, where there were no hills near to give the wind an up-tilt, the nearest sierra being twenty miles distant. There I watched through a field-glass the eagles and the kites describing their spirals as they ascended into the blue of heaven, even the outspread remiges, the great wing feathers, with lanes of daylight between, being clearly discernible.

Once more let us consider the wind and its unseen vagaries. Even if there is no tilt of the wind due to mountains, there may be ascending currents when the surface of the earth becomes heated by the sun, and the air, heated by contact with the earth, mounts upward owing to its greater lightness. Those who have made a study of clouds tell us that the great cumulus clouds (they increase in size from the bottom upwards) are the tops of ascending currents of air that rise from the ground. Warm air can carry more moisture than cold air, and when these ascending currents become chilled through mixture with colder air above, or by expansion, the moisture in them is condensed, formed, that is, into small drops of water or minute snowflakes. The formation of clouds owing to the heating of the earth takes place well on in the day, say from noon onwards. The cumulus form of them makes it probable that the upward-moving air breaks up into well-defined streams capped by these clouds, while in the interspaces there are descending currents. Certainly, if anywhere we find an ascending current of air, we may feel sure (though Lilienthal could not see this) that somewhere not far off there must be a corresponding downward current.

Have we in these up-currents of heated air the key to the great problem of the soaring of birds over plains? Near Cairo I saw the Kites soaring as early as nine in the morning, before the sun had time to heat the earth's surface and set the air in motion. The hills were quite five miles off, and now that I have seen at Biskra and elsewhere how rapidly an upward slope due to a hill ridge is lost by the wind, I am not inclined to believe the kites had any assistance from this source. Near the Guadalquivir I do not remember any soaring very early in the day, though, probably, it did take place. But is a current of heated air from the earth's surface likely to be strong enough to lift a bird? It must not be forgotten that they are no mere feather weights, still less are they mere balloons. If the upward and downward movements of air form definite currents, as is suggested in the article in the *British Encyclopædia*,[1] from which I derive my information about clouds, they may be stronger at some height than we on the earth's surface are apt to imagine. That is certainly possible, and it would help to explain why in hot southern regions there is more soaring over plains than in the colder north. I believe (certainly I myself have never seen it) that there is no soaring over the open sea. The surface of the sea gets less heated than the land surface, so that up-currents of air are less likely to occur there. Certainly it is curious that the birds of the ocean do not soar, at any rate over the regions that properly belong to them. The albatross, the gull, and, I think, also the frigate bird, are very clever at getting the wind to lift them. But the albatross and frigate bird, I believe, do not soar, while gulls turn their spirals only when a cliff makes the conditions favourable. Against this view—no up-current, no soaring—we may put Mr Peal's evidence that he has seen tufts of cotton passing horizontally over the field of the telescope when the adjutants have been soaring; to which the reply has been made that at a great height one cannot be certain about the line along which floating cotton travels. It cannot, however, have been moving vertically upward, or even along a line near to the vertical. But the strongest argument is the fact that they soar only when there is a wind blowing. It is difficult to believe that a wind sweeping over a vast flat plain is far from horizontal. On the whole it seems to me that the noblest soaring is achieved by the help of a horizontal wind, though, in that case, the fact that we never see birds rise in spirals over the open sea remains very difficult to explain.[1]

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[1] Vol. xvi. p. 127, in the article on *Meteorology*.

Let us suppose, then, that a horizontal wind is all that is available. Of one thing we may be quite sure, that if it is uniform in velocity it will be of no use to the bird, he will be no more helped by the wind to rise than is a kite when its string has been broken. If, however, there is an increase in the velocity of the wind with altitude, so that the bird as he rises is always passing from a slower to a more rapid current, then things will be different. He will have inertia, due to his being part of the more slowly moving stratum of air from which he has just emerged, so that he will not be carried by the air like a balloon, but will be, on the contrary, like a kite with a string. This sounds admirable, but now for a douche of cold water on this theoretically excellent explanation. At the great heights at which birds often soar, the increase in velocity with altitude, as experiments have proved, is so trifling that it will be of no use (see p. 158). For the snipe rising from his marsh, or the cormorant rising from the sea, the increase with altitude is a lift-up, but for the soaring adjutant or kite it is of no use.

We must, therefore, look for another explanation. The wind may be irregular in another way. It may vary in pace from moment to moment, or half minute to half minute. Even in a steady wind there is great unsteadiness, as Professor Langley has proved by means of experiments with a delicate anemometer. One experiment showed that, at a height of fifty-three feet, the velocity of the wind measured at intervals from seven to seventeen seconds, varied from ten to twenty-five miles per hour. On one occasion he found that a wind blowing forty miles per hour would drop almost in an instant to a calm. His anemometer stopped dead for one second in a high wind. "Another trial, when the velocity was measured every second, showed that a wind of twenty-three miles an hour may in ten seconds rise to thirty-three miles, within ten seconds fall again to twenty-three, then in another thirty seconds rise to thirty-six."[1] What is the cause or the nature of these fits and starts? Why does Æolus blow now with his fullest power, then, apparently, tire and blow gently? "The onward movement of a large volume of air cannot be suddenly checked; but it may well be that the irregularity is due to eddies, the anemometer in an apparent lull being really in the centre or the back current of an eddy, whereas during what seems a sudden gust it is in the eddy's onward sweep."[1]

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[1] See next page.

Whatever the cause of the irregularity, the bird has, I think, what is wanted for soaring purposes. He must be an adept at utilising capricious gusts, and we know that he is that. Let us assume that eddies, the most probable explanation, account for the irregularity. Let us further imagine that they are of sufficient size; no unwarrantable assumption, since several people standing at some little distance from one another often feel a sudden gust simultaneously. The cue for our bird now (adjutant, stork, eagle, vulture, pelican, kite) is to fly *with* a dropping breeze, then, directly he feels it rising, turn and face it. Armed with the inertia of the slow current, he will turn and present his under surface, inclined upward, to the rising breeze. Being, then, a kite with a string (I reiterate this *ad nauseam*, because everything depends on it), he will be able to set the parallelogram of forces to work, he will break up the force of the wind into two forces, one lifting him upward, the other driving him backward (the leeway of which Mr Peal speaks).

Since writing the above, I have seen a certain amount of soaring, and again turned the question over. The slow, majestic way in which the great performers turn their spirals, certainly suggests balancing and rising on an up-current, rather than the utilising of the wild gusts of a horizontal eddy. The birds seem to prefer a rather gentle breeze. And this, though we must allow for its greater velocity at a greater altitude, is an argument in favour of an upward trend in the wind. A horizontal wind, if it is to have lifting power, must not only be strong, but must have great irregularities of pace, and such a wind seems out of keeping with the calm gyrations of the adjutant.

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[1] I quote from my *Structure and Life of Birds*, p. 237. See the *Internal Work of the Wind*, by Prof. S. P. Langley, *American Journal of Science*, January 1894.

Here, then, we must leave the question of soaring. Possibly in the noblest exposition of the art it depends on a horizontal but irregular wind. But it is probable there may always be up-currents to account for it. Why not, in the great plain of Upper Assam, when soaring is actually taking place, investigate, by the aid of balloons or man-lifting kites, on the scene of action, instead of trying to argue it out down below? It only wants money, leisure, and enterprise, three things which ought to be available.

A note on the comparative power of flight of big and small birds. Helmholtz undertook to prove mathematically that a really big bird could not possibly fly. If the supporting area is increased, the bulk, he argued, must increase disproportionately (see fig. 64, p. 123). But Mr Maxim's flying machine, weighing over three tons (a very big bird!) rose in air. We must allow the area and bulk argument, but size has compensating advantages: this among others, that a long wing will move more rapidly at the extremity than a short one. The difficulty of the cormorant in rising is largely due to the small amount of rotation at the shoulder joint that is possible for the wing. He cannot rotate it as a lark does, lowering the front margin, when, with his body at an angle of about 60° to the horizon, he rises in air. If a cormorant inclined his body thus, his wings would beat backward. I have investigated the amount of rotation possible for the wings of many birds, and have found it very small in the big kinds which fly well, but rise with difficulty. Small birds never soar, probably because a small wing, though it can give a forceable stroke, is a bad parachute: the air slips away from underneath it.

Chapter VII

THE MINDS OF MEN AND ANIMALS

The First Beginnings of Mind

The greatest minds

MENTAL evolution has culminated in such giant intellects as Shakespeare, Newton, and Darwin. I single out these names rather than those of great men of other nations, because we are, or ought to be, to some extent familiar with their work. Let us try to imagine Shakespeare creating what we are familiar with as a thing finished and complete, creating Hamlet, which we know as a series of rarest crystals of thought, but which, at the time we are picturing to ourselves, was, part of it, uncrystallised; as yet but thoughts, flashing up to the surface for a moment of life, and, as they appeared in turn, caught and not allowed to die—things in their nature ethereal and fugitive, caught and preserved by means of ink and paper, for man to rejoice in and ponder over.

There are also crystals of thought which represent to us the working of the minds of great men of science. Such crystals are far-reaching discoveries that help us to understand the phenomena of nature. The contemplation of great thinkers, whether poets or men of science, especially when, instead of looking at their finished work, we try to picture to ourselves the mental forge that turned out the work, makes us sometimes stand aghast, like a man who, on a clear night, gazes at the Milky Way, and in the presence of so many solar systems feels his own insignificance beaten into him.

In the poet and the man of science we see mind at its highest and noblest. But our present business is not to stand awestruck before the great achievements of the human intellect, but to consider its evolution. Not only man has a mind. Monkeys, dogs, elephants, and others that we speak of somewhat contemptuously as the lower animals, have what we are bound to define as minds. They are *bornés*, no doubt. Abstract ideas are, perhaps, impossible for them. They are, let us grant, limited to the concrete; still they have minds. They choose this, reject that, they learn by experience. But if they—monkeys, dogs, elephants—have minds, beyond all dispute, in what animals are we to look for the first beginnings of mental evolution? This is a difficult question to answer, but it will not do to shirk it. Let us first find a criterion of mind. I adopt as criterion the power of choice. No doubt the power of learning by experience, where it can be proved, is a more indisputable test, but there are cases where the evidence for this fails us. There may be a learning from experience or there may not, yet there is an indubitable power of choice. Let us take an instance. Once more let the Amœba appear on the stage (see p. 9). This wonderful microscopic animal, a minute blob of protoplasm forming a single cell, has beyond dispute the power of choice. It exercises this power whenever it eats. Its favourite food consists of minute vegetables called diatoms, encased in an envelope of flint (see p. 5). When an amœba comes in contact with a diatom, he often swallows it. He makes an aperture, a mouth, where a mouth is required, and the diatom passes into his interior. But when he comes in contact with a small grain of flint he does not treat it as he treats the flinty envelope of the diatom. He leaves it alone. We can hardly put this down as a matter of mere chemistry. It is not like the refusal of oil and water to mix. Nor is his taking of what he wants for food at all similar to the rushing together of the atoms of oxygen and hydrogen to form water.

A criterion

But there are among the infusorians some which are much more conspicuously hunters than the amœba. In Binet's *Psychic Life of the Micro-Organisms*[1] (a bold title, but, I think, justified by facts) will be found an account of the predatory methods of an infusorian called Amphileptus meleagris. Like other infusorians (see p. 12), Amphileptus swims by means of minute threads called

A hunter infusorian

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[1] P. 50. He quotes from Claparède and Lachman's *Études sur les Infusoires et les Rhizopodes*, vol. ii. p. 166.

cilia. M. Binet quotes a description of his attack on Epistylis plicatilis, one of the infusorians that anchors by means of a long stalk (see figure 90 for something resembling it). "The way in which it approached the vorticels, feeling them, so to speak, and partly enclosing them in its pliable body, already seemed suspicious. At last it made a direct attack upon one of them by fastening itself upon the upper part of its body. It opened its huge mouth, which is never to be seen except when the animal is eating, and slipped over the epistylis like the finger of a glove being drawn upon a finger of the hand. . . . It then endeavours to wrench the epistylis from its point of attachment by twisting. . . . When it has succeeded, it continues the work of digestion." I once found an Amphileptus (A. anser—its long neck suggests a goose, but it is too clever for such a name) with a good-sized rotifer[1] inside it. Figure 89 shows him engulfed. Rotifers or wheel animalcules are animals of a higher class, having mouths, gullets, stomachs, bands of muscle, brains, and, many of them, eyes. They are big enough to be seen beneath a lens multiplying, say, six times. But Amphileptus anser, being wonderfully elastic, had got round his rotifer, as a boa constrictor, with effort, manages to swallow a duck that seems much too big for him.[2] I wish I had seen the process. Another infusorian, Didinium nasutum, is a mighty hunter. M. Binet describes his methods of attack. It swallows infusorians nearly as big as itself.[3]

Some infusorians, then, go a-hunting, and they hunt in a way that shows that they have intelligence. Those who belittle them are, as a rule, those who have not watched them at work. They talk of chemical reaction. But this supplies no explanation of the behaviour of amphileptus or even of amœba.

Muscular power, nerve power, senses, in micro-organisms

Let us now approach the question of the intelligence of the micro-organisms from another direction. They have, in an extremely rudimentary form, other powers which we find highly

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[1] Of the genus Metopodia.

[2] Amphileptus, without his neck, is about $\frac{1}{100}$ inch long; Metopodia, without his foot, about $\frac{1}{150}$.

[3] For a fuller account of Didinium nasutum, see a paper by E. G. Balbiani in *Archives de Zoologie Experimentale*, 1873, vol. xi. p. 363.

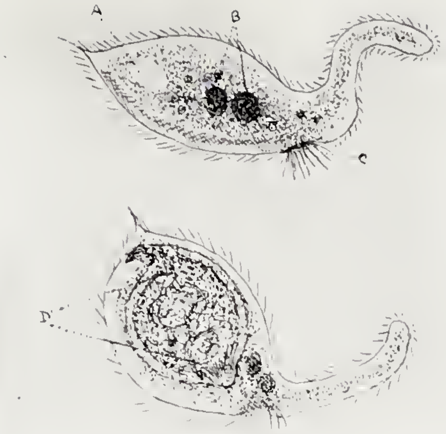

FIG. 89.—Amphileptus anser (partly after Ehrenberg)—A, contractile vacuole; B, nucleus; C, mouth; D, rotifer (metopodia) ingested. Length of Amphileptus without neck $\frac{1}{100}$ inch, rotifer $\frac{1}{150}$.

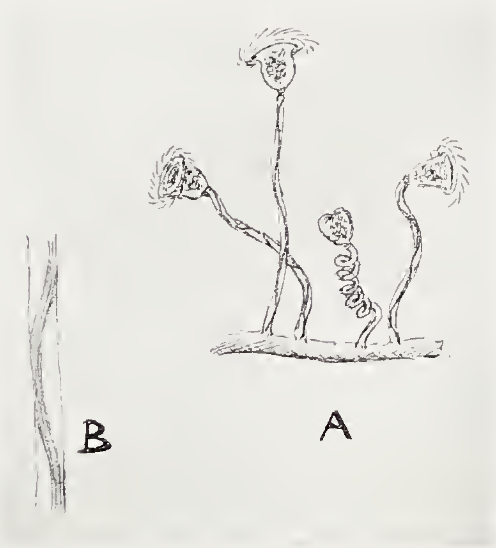

FIG. 90.—Vorticella or Bell Animalcule. A × 90 diameters; B × 240, shows the spiral muscular fibre.

developed in man. If they have the rudiment of these, is it not probable that they have a rudiment also of intelligence? Take first muscular power. Vorticella, one of the fixed infusorians already spoken of, has a curved band of protoplasm running down the interior of its stalk (fig. 90, p. 176). It is striated like muscle, and certainly it has muscular power. The slightest jar, the slightest vibration in the water, and vorticella contracts the muscular band in spirals, and so shrinks up as close as he can to the duckweed or whatever it is which forms his pedestal. What is this sensitiveness to the slightest vibration but undeniable nerve-power? And how do vorticellas' movements, thus set going, differ from our own muscular movements? Then, again, the rapidly-swimming infusorians are very clever at steering. They never cannon against one another or charge into obstacles. The common Paramœcium (see p. 12) is a good instance. Probably this power of steering is due to a delicate sense of touch or some generalised sense. When they get near an obstacle probably they feel that something is checking the movement of the water in which their cilia make waves and eddies as they dash hither and thither. Some of them are sensitive to light, notably Euglena (see p. 14). It has a red spot, which is sometimes called an eye spot. Some authorities are of opinion, however, that their sensitiveness does not reside there, but somewhere else in their very small persons—from our present point of view a mere academic question. They do make for the light, and profit by it too, for it enables their chlorophyll to obtain carbon for them. In some of these micro-organisms the activities are as perfectly co-ordinated as if they had a central nerve organ, a brain, in fact. This is notably the case with Volvox globator, found plentifully in our ponds (fig. 3, p. 8). It is a sphere formed of a network of cells. Each cell has two cilia, and these many cilia move like one, keeping perfect time, causing volvox to roll comfortably on.

Digestion and assimilation

The micro-organisms certainly have the power of digestion and assimilation. The amœba swallows his diatom, extracts, digests, and assimilates the juicy protoplasm and ejects the flinty envelope. What more can we do with all our elaborate digestive apparatus? Certainly the micro-organisms breathe. Though they have no blood corpuscles, no specialised fluid corresponding to our blood, yet oxygen is a necessity to them no less than to us. They cannot live in water which contains no free oxygen any more than a fish can.

A priori

We see, then, that these minutiæ, most of them formed only of one cell of protoplasm, have muscular power, nerve power, sensitiveness to light, sense of touch or some sense not definitely specialised, power of digestion and assimilation, and that they breathe though they have no lungs or gills. If they have the rudiments of all these powers which are highly developed in us, surely we ought to be ready to accept evidence of their having rudimentary minds when such evidence presents itself. Now this evidence is at hand. The amœba evidently chooses its food, chooses the diatom, and rejects other things. Amphileptus shows skill when he goes hunting. Whether consciousness accompanies these activities it is difficult to say. Probably it is there, a dim twilight consciousness, with no sharp definition. But when we see them displaying skill and exercising choice, it would be absurd to deny its existence. Yet it is very commonly denied, and possibly for this reason. We have a chain of nerve ganglia at intervals all along the spinal cord, and each of these ganglia is far more highly developed than an amœba or amphileptus, neither of which has any tissue specialised as nerves. That these ganglia are actively operative is proved by a common experiment. A frog's head is cut off. Then a drop of strong acid is put upon its thigh or body. It will at once try to rub this acid off with its foot, some lower nerve ganglion guiding its movements. If the foot or the leg in question is cut off, finding the stump useless it will use the other foot. In the same way, many of our own movements are automatic, and are not directed by the brain, but by one of the lower nerve ganglia; and since these nerve ganglia, more highly developed than anything an amœba or amphileptus possesses, set muscles in motion without any concomitant consciousness, it might be argued that amœba and other creatures of the same level must live an unconscious life. But our nerve ganglia

The question of consciousness

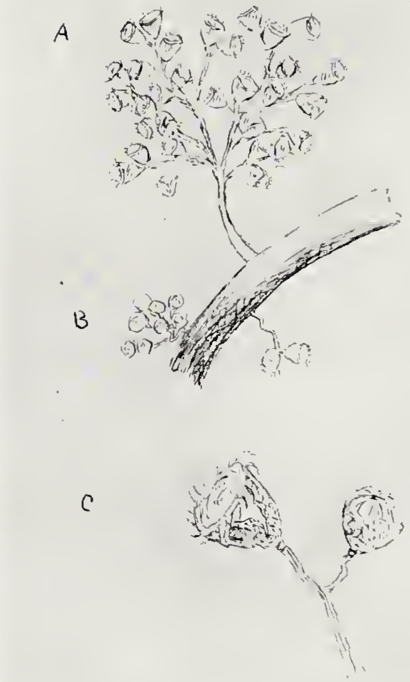

FIG. 91.—Zoothamnium arbuscula—A, expanded, B, contracted (× 40 diameters); C (× 200), a hunting and feeding zooid on left, a reproductive zooid on right.

may have, each of them, a consciousness of its own, unknown to us in whose service they work. Their consciousness is eclipsed by a more brilliant light, by the consciousness of the brain. With the loss of independence, being as they are mere subordinate parts of a complicated machine, they have, no doubt, lost much. All the more important questions which involve the balancing of alternatives are settled for them by the brain.

Learning by experience

It is now time to ask another question about the one-celled organisms. Do they learn by experience, by a system of trial and error, as it has been called? It is very difficult to devise an experiment that will find the true answer to this question. But I have experimented on an organism that ranks only a very little higher in the scale, and found good evidence of what we should call in one of the higher animals a power of learning, of profiting by experience, a thing impossible, it is generally considered, without intelligence.

Zoothamnium arbuscula is an infusorian, found both in fresh and salt water (fig. 91, p. 179). It is fairly frequent in Norfolk Broads. It sometimes coats the sides of sea-water aquariums. Most infusorians are one-celled organisms that swim by means of cilia or larger threads of protoplasm called flagella. Zoothamnium is a tree-like colony of such units. Up the stem and along the branches run thin lines of muscle longitudinally, and possibly also transversely, striated, but not spirally twisted as it is in vorticella. The members of the colony, called zooids, are of two kinds, one ciliated, the other having no cilia and existing for reproductive purposes. There is, therefore, something in the way of specialisation. But, after all, zoothamnium is hardly more than an association of individuals which, singly, cannot rank above an ordinary unicellular infusorian. This colony of zooids lives fixed by its stem, and the stem, with its band of muscle, is wonderfully contractile. At the slightest suspicion of danger the expanded "tree" will, as a rule, shrink back into a small compass. When a colony of zoothamnium is put in a small tank it expands, and its various zooids are on the look-out for any tasty microscopic kickshaws that they may be able to sweep into their insides. But if the tank is jarred the stem and branches contract, and there is an instantaneous collapse, then a comparatively slow re-expansion, to see if the coast is clear again. Here was a chance for experimenting. When the tank has been jarred three or four times, and each jar has been followed by an instantaneous withdrawal and then a re-expansion, the zoothamnium begins to realise that there is no danger, and no longer withdraws, or at any rate requires a much more violent shock, or a number of quickly-repeated shocks, to make him retreat. He learns by experience that the jarring does not mean that there is any danger at hand. Even in such simple organisms there are varieties of individual character.[1] I speak of a colony of zooids as an individual, because it generally acts as a whole as if controlled by a centralised nervous system. Some individuals are much less sensitive than others. From the very first they take little notice of a jar. In some, one branch of the tree is more sensitive than the rest—a want of centralisation. Of one, I have noted that one part seemed to have a longer "memory" than the rest. This part "remembered" for a minute or so that shocks meant nothing, and did not withdraw. From such experiments we cannot help concluding that these colonies of unicellular zooids are capable of learning by experience. Usually it is the collective colony, occasionally part of the colony separately. And further, we cannot help inferring that one-celled organisms that do not live in colonies have a power of learning not greatly, if at all, inferior to that of zoothamnium. On this subject I would refer my readers to Mr Jennings' book on *The Study of the Behaviour of Lower Organisms*, where he shows that a Stentor, a large trumpet-shaped infusorian, can pass from one "physiological state" to another.[2]

The process of learning

Having got so far, we might appropriately discuss the process of learning. How is it possible to learn anything? We get so used to learning, to profiting by experience. We are so constantly told that learning is easy that it hardly occurs to us to puzzle over the process. But at present I will only touch upon the subject, speaking very briefly of attention and memory, two faculties without which no learning is possible. The further consideration of the process of learning I shall put off till I come to the psychology of the higher animals.

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[1] The common vorticella might be experimented on in the same way.

[2] See p. 113. It is published by the Carnegie Institution of Washington.

Attention

When we attend closely to a subject, the essential thing is that we inhibit all other activities of the higher regions of the brain, so that our thoughts are fixed on the matter in hand to the exclusion of all disturbing influences. A one-celled organism has no localised brain, and obviously nothing corresponding to these higher regions. His machinery seems too simple to allow us to think of part being hard at work while another part is idle. Still, when he goes hunting, there may be, however it is effected, an inhibition of activities that are not needed, and a consequent concentration upon the chase. Because we cannot see and explain the machinery, we must not speak of it as non-existent. Indeed the work is somehow done. There must be machinery, however difficult it may be to imagine what it is. We cannot help conceding to the micro-organisms a rudimentary power of attention.

Memory

Memory is closely allied to attention. Attention enables us to hold a picture before the mind to the exclusion of all irrelevant things. Memory recalls mental pictures after they have passed from our consciousness. Our brains consist of a number of different compartments, not only, I mean, those which are anatomically distinguishable, but hundreds of different metaphorical pigeon-holes, the existence of which we can infer from the way in which the brain works. In these pigeon-holes are stowed away ideas, mental pictures we have formed in the course of our lives, and many of these ideas are connected one with another. Thus one idea, to use Professor Mark Baldwin's expression, rings up a connected idea. And this is what we call memory. A notice "Warning to Cyclists" at the top of a hill awakens perhaps an associated mental picture of shapeless wheels and broken legs. When I heard on a steamer crossing the Atlantic the remark, "I am an awful crock at Latin," it called up before my mind's eye the picture of a big quadrangle, with a chapel dome rising on the south side. Since memory depends on the linking of ideas, it is difficult to see how it can be much developed in creatures which, so far from having complicated brains, have no brains at all, not even any nerves, but only nerve power diffused through their one minute cell. Still it would be rash and unscientific to assert that an amœba cannot possibly have any rudiment of a memory. Certainly my zoothamnium seemed to learn by experience. It "*remembered*" that no unpleasant consequences followed when it felt a jar. These jars became associated in its "mind" with safety if not with complete comfort. These are just the terms in which we should explain such conduct if we were speaking of one of the higher animals. Then why should we resort to a different explanation when we are speaking of a unicellular organism?

Résumé Let us now survey the conclusions at which we have arrived. The micro-organisms have minds. We infer this from the way in which some of them choose between this and that, in cases where chemistry seems to offer no explanation. Further than this, judging by what zoothamnium, a creature which is hardly on a higher level than many one-celled organisms, can do, we may feel sure that they are able to learn by experience. A priori, too, we cannot help considering it probable that they have intelligence, arguing in this way: undoubtedly they have muscular power, nerve power, power to digest and assimilate, so that we are led to the conclusion that organic evolution produces nothing absolutely new, but only specialises and perfects what already exists in the simplest forms of life. We might expect, then, that it would find in them and develop a rudimentary intelligence, just as it finds existing a rudimentary muscular power and develops it. Probably, too, the micro-organisms have a dim consciousness. Intelligence and consciousness, therefore, we make co-extensive with animal life. Probably we ought to extend consciousness further, but in a form still more dim and rudimentary, to vegetables. As to the process of learning, we can see some rudiment of attention in the way some infusorians hunt. As to memory, we can find a beginning of it in zoothamnium, though it cannot advance far till the brain becomes a complicated machine with a number of different centres.

These are rather startling conclusions till you get used to them. They are still more startling when you consider what assumption we make when, from an infusorian's conduct, we infer that he has a mind. The argument is: "If we lived under such conditions and had similar wants, our intelligence would lead us to behave like that." We use, each of us, our own character, the only one which we know, to interpret the actions of an amœba. A very elaborate key to open a comparatively simple lock, but it is the only one which we possess. The highest class of intellect which evolution has produced has to investigate the lowest, on the assumption that there is a unity in nature, and that the same principles hold true whether we are trying to understand the psychology of a man or an infusorian.

Our means of judging of the minds of micro-organisms

In order to make it clear that our own character and nothing else must be used as the key to that of other persons or other organisms, consider for a moment the intellectual development of a baby. At first he sees no difference between persons and things. But at last it dawns upon him—it must be so though we have all forgotten the moment of this great discovery—that some objects he comes in contact with are always the same, *e.g.* fire, a brick wall, a bed, whereas others vary from day to day. They have varying moods. And so he comes to distinguish them as *persons* from *things* which do not vary. Then it dawns upon him that he himself is a person and not a thing. It must be so, for we have all of us this idea clearly formed about ourselves, although we have no idea when we arrived at it. The next step for our infant is to assume that other persons are like himself. And so begins the process that continues throughout life, the interpretation of the characters of other people in the light of his own. Hence the very different views men form of the world. The keys they employ to interpret what they see are so diverse.

The question is now: What is the character of an amœba? We must have recourse to the same key that we should use if we were in doubt about any man we might come in contact with. Is he an honest man? Or a thief? A dullard? Or a man of brain? In the light of our own character we must interpret everything, even the action of an amœba—using, as I have said, a very delicate key for a very primitive and simple lock that very imperfectly displays its mechanism. But in so doing we are only making the quite justifiable assumption that all living organisms are akin.

The Higher Animals

We now leave the micro-organisms and consider the activities of animals higher in the scale. It is necessary at the outset to distinguish different classes of movements and actions. There are some which are called reflex, others which are instinctive, others again which are intelligent. It is easy enough to define them, the difficulty arises when we have to judge of a particular action and decide in which class to put it.

Reflex actions

Reflex actions go on independently of the brain. A frog, as I mentioned above, will after the removal of his brain use his foot to rub off a drop of acid that has been put on his body. An afferent nerve current passes from the spot irritated to a nerve ganglion in the spinal cord, an efferent nerve current sets the leg in motion. There is no consciousness accompanying the action unless the nerve ganglion has a consciousness of its own. The frog's brain, meanwhile, the centre of life and consciousness, is beyond the reach of experimenters and all the ills that flesh is heir to. Blinking, when something, *e.g.* a fist, suddenly appears in close proximity to the eyes, is a familiar instance of a reflex movement. Similar to this is the movement of the iris which lessens the diameter of the pupil of the eye when a bright light falls upon it. The sudden drawing back of the hand when it grasps an excessively hot plate is another. Here there is consciousness, but this is not necessary to the action, for, to take a similar case, if we accidentally protrude a foot from under the bedclothes during sleep, we withdraw it sometimes without waking. However, in this case there may be what is called subconsciousness. The movements of the intestines are entirely reflex. They take place independently of our will. Similarly when a crumb gets into the windpipe it is ejected by reflex action, though the accompanying irritation gives rise to consciousness. What is meant by the word ought now to be clear. But there is one complication still to be mentioned. In some cases a reflex, though due to the working of involuntary muscles, is partly controllable by the will through the working of associated voluntary muscles. The movement of the intestines is a case in point. On the other hand, the distension and contraction of the arteries to allow a greater or less flow of blood is quite independent of our will. Snowballing makes the hands glow whether we like it or not. The withdrawal of zoothamnium when his tank is jarred is probably a mere reflex. When the jarring is repeated he brings the reflex under control. So, at least, we should explain such conduct in the case of one of the higher animals.

Instinctive actions

Instinctive actions are in some cases easily confused with reflexes. But there is always this difference about them, that they involve the activity of the whole animal, not, like the reflexes, that of a part of him only. We find the most perfect instincts, some of them diabolically perfect, in insects. When a queen bee emerges from the cell, her first instinct is to rush to the other cells which contain the queen pupæ—she knows them by their greater size. If she is not baulked by the workers she tears open the cells and kills off all possible rivals. There are solitary wasps which insert their sting into the nerve ganglion of a spider so as to paralyse it but not kill it. Then she, the mother wasp, stows it in the cell in which she places her egg. The paralysed spider remains fresh till the wasp grub hatches out and is able to banquet on the food his mother has stored up for him.

On the Instincts and Habits of the Solitary Wasps is a first-rate book[1] to which I would refer the reader who is interested in this object. The authors find in each species strongly marked instincts which yet allow a good deal of freedom for the play of individual character and vagaries.

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[1] By G. W. and E. C. Peckham, 1898.

The Sitaris beetle performs a series of wonderful actions, being guided throughout by instinct, for no other explanation is possible. A good account of this extraordinary beetle, founded on the observations of M. Fabre, will be found in Professor Lloyd Morgan's *Habit and Instinct* (p. 15). I borrow the substance of this from him. The Sitaris lays her eggs at the entrance to the nest of a kind of Mason-bee. The larvæ hatch out in autumn, and, remaining sluggish till the next spring, await their opportunity. This comes when the drones go out of the nest. The beetle grub, having a sharp curved hook at the end of each leg, clings to one of them. When the drone mates with the female bee in the air, the beetle grub leaves the drone and transfers himself to the female. When the female lays an egg, the Sitaris opens another chapter of its life history, jumps on to the egg and begins to eat it. The mother fastens up the young robber in a cell with her egg. The egg floating on the honey serves both as raft and repast. Soon the Sitaris is transformed to a white fleshy grub which floats on the honey with its mouth beneath and the spiracles above the surface. Thus it breathes and gorges till there is no more honey. Some further metamorphoses and in August it is a perfect beetle. An almost equally marvellous series of instinctive actions we may find in the life history of the Yucca moth, which is told in Kerner's *Botany* (vol. ii. p. 156). An example of instinct no less wonderful in its way and familiar to all is the silk moth caterpillar's spinning of its cocoon.

In some of the examples of instinct I have given the action is performed only once during life. The caterpillar spins only one cocoon. The Sitaris has only once to attach himself to a drone, only once to go through the elaborate programme that I have detailed. Only once does the queen bee emerge from the cell and set about gratifying her murderous instinct. The solitary wasp, though she may sting many spiders, yet is probably as perfect in the art at the first essay as at the last. The reproduction of the species is entrusted to the care of instincts which are perfect without practice. It is too important a matter to be left dependent on skill gained by a number of blundering attempts. The cuckoo knows by instinct what to do with her egg. She lays it on the ground, then pops it into a suitable nest. We can hardly believe that her mother, having left her to the care of strangers during infancy, instructs her next year in the duties of motherhood. Nor is it likely that the young mother watches an older one disposing of her egg and copies her. For in that case we should find, more often than we do, two cuckoos' eggs in one nest.

These perfect instincts that require absolutely no practice are marvellously clever, but once interrupt one of these wonderful insect artists and the mechanical nature of the performance becomes apparent. To show how true this is, I give a quotation from Mr Romanes' *Mental Evolution in Animals*. "In repeating anything by heart, or in playing a tune, everyone feels that, if interrupted, it is easy to go back a little, but very difficult suddenly to resume the thread of thought or action a few steps in advance. Now P. Huber has described a caterpillar which makes by a succession of processes a very complicated hammock for its metamorphosis; and he found that if he took a caterpillar which had completed its hammock up to, say, the sixth stage of construction, and put it into a hammock completed up only to the third stage, the caterpillar did not seem puzzled, but repeated the fourth, fifth, and sixth stages of construction. If, however, a caterpillar was taken out of a hammock made up, for instance, to the third stage, and put into one finished to the ninth stage, so that much of its work was done for it, far from feeling the benefit of this, it was much embarrassed and even forced to go over the already finished work, starting from the third stage where it had left off."[1] On the other hand, when an artificial foundation for their comb is supplied to bees, they gladly avail themselves of it and never dream of making one.

We can now venture on a definition of instinct. A perfectly instinctive action is one which is performed without practice. All members of a species have similar instincts, and their instinctive actions are closely similar. But, of course, there are occasional variations, otherwise there could be no progress.

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[1] P. 179. Mr Romanes is quoting from Mr Darwin's MSS.

Instincts involve the activity of the whole organism, not, like reflexes, that of part only. I cannot help believing that they are guided or accompanied by consciousness, though it is impossible to prove this. It is difficult to imagine a caterpillar spinning his cocoon entirely unconsciously. If the series of stages is interrupted, as in Huber's experiment, no doubt the caterpillar pauses and reflects, however wrongly he may decide. I say "reflects" for want of a word that fitter describes the workings of so poor a brain. But short of such violent interruptions, it is probable that small problems arise in the course of an apparently uninterrupted spinning operation. An instinctive action, then, is an activity of the whole organism, performed similarly without previous practice by all members of the species, and I myself should add that this involves the presence of consciousness.

The modification of instincts

As yet we have been talking only of actions which are perfectly instinctive. The possibility of learning or practising is excluded in many cases, since they are performed without instruction and only once during a lifetime. There are other instinctive actions which are modified by practice as life goes on. A young bird sings the song of his species by instinct, but in most cases the instinct requires to be awakened. If isolated he will sing but fragments of the song of his kind, or not even fragments. But when the songs of scores of birds are ringing through the woods around him, his own proper song comes to him at once. Some species, starlings for instance, constantly mimic other birds. Chaffinches, on the other hand, never deviate from their own tune. But to all of them their own proper song comes easily directly they hear it, though they improve by practice. The singing of birds, therefore, we may describe as imperfectly instinctive. Nest-building undoubtedly depends on instinct. As a nestling the young bird only saw the finished structure, and at that time, being intent only on sleep and eating, he did not care to study architecture. There are accounts of young birds when transported to other countries failing to build the kind of nest proper to their species. This may show that the sight of the nest of its own kind at the season of building is required to awaken the instinct in a bird that has to try her 'prentice hand.

But if the mere sight of a nest is instruction enough, the skill shown is almost purely instinctive. Imagine a pair of chaffinches, clever as they are at their own particular kind of building, trying to build in the style peculiar to the long-tailed tits. Nest-building cannot, then, be a matter of learning, that laborious process so familiar to us. It is instinctive, though it may require in some cases just a trigger touch to fire off the chain of activities. Even a canary that has been brought up in an artificial nest of felt will set about building a nest for herself in fairly good style the following spring.

Many experiments have been made on young chickens hatched in incubators, with a view to discovering what equipment of instinctive skill they have at birth, and how much they have to learn. Professor Lloyd Morgan gives a very interesting account of his experiments in his *Habit and Instinct.* It came out very clearly that pecking was instinctive, and they never pecked at objects beyond their reach, though their aim was not always quite accurate. When we consider how many muscles have to work in harmony, in obedience to the brain, in order to bring about this apparently simple result, a well-aimed peck, we may reasonably wonder at the close approximation of the instinct to perfection. I cannot help thinking too that the failure to aim accurately was often due to weakness. If the chickens had been fed by hand for a day or two without being allowed to practise pecking, they might have shown in their first essays perfect accuracy of aim. When it came to a question of distinguishing things good for young chicks from things bad, they were all at sea. After much relishing some worms, young chicks have been known to mistake pieces of worsted wool of similar colour for the succulent creatures they had just been eating;[1] they swallowed some pieces, felt uncomfortable inside, and avoided wool for the future. Young chickens, uninstructed, peck at everything by way of experiment, anything of suitable size, "grain, small stones, bread crumbs, chopped up wax matches, currants, bits of paper, buttons, beads, cigarette ash and ends, their own toes and those of their companions, maggots, bits of bread, specks on the floor, their neighbours' eyes."[1] Cinnabar caterpillars, which are nauseous and are armed with warning colours, alternate rings of black and yellow, were experimented with. The chicks seized them but dropped them uninjured, wiping their bills, which is their way of expressing distaste. Young moorhens are born with some of their powers fully developed. Not long ago I found a nest in which there were four eggs and three young ones. Probably, therefore, the young birds had very recently made their way out of the egg. Yet on noticing my approach they at once jumped into the water, swam away and hid themselves among the waterweeds. They seemed to swim perfectly, but probably they improve in the art with practice. When a young swallow first jumps from the nest he at once shows himself an adept at flight. But he is not so good at sudden twists and turns, the great accomplishment of the swallow, as his parents. Many birds, notably gulls and the great soaring birds, spend a great deal of time in the air perfecting themselves in the noble art of flight.

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[1] I think these were Professor Lloyd Morgan's chicks, but I am not sure.

All mammals suck the breast by instinct. Yet Mr Wesley Mills,[2] who has made careful observations on young puppies, states that the instinct in them is not perfect at birth. At first they would suck anything, *e.g.* a finger, though they would leave off when they found that no milk came. After two weeks the feet are much more skilfully used to press the mammary glands.

The snubbing of instincts, and formation of habits

Instincts may be snubbed till an acquired habit supersedes them. I take an instance from bird life. It is natural to a hen to keep her young chicks on dry land. She herself has an instinctive dislike of water except for drinking. Yet a hen who for three successive years had sat on ducks' eggs came to think it right and proper that her brood should take to the water. She would fly to a stone in the middle of the duck-pond and call them to her. The fourth year she was put to sit upon her own eggs. She flew to the stone and expected her chicks to swim to her as her ducklings had done.[3] There is another apparently well authenticated story of a hen, on whom a similar experiment had been made, actually pushing her chicks into the water.[1]

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[1] *Habit and Instinct*, p. 40.

[2] *Transactions of the Royal Society of Canada*, 1894.

[3] Quoted from Jesse's *Gleanings* by Romanes, *Mental Evolution*, p. 215.

Crabs as learners

Even animals of a much lower order than chickens are capable, when taught by bitter experience, of snubbing their instincts and forming new habits in place of them. In September 1905 I made some experiments on crabs of various species, and was able to prove that they had a remarkable power of profiting by experience. This is a very interesting fact, since anyone who has dissected a crayfish, a lobster, or a crab, knows how extremely small is the organ which does duty as a brain even in those highest of crustaceans.

The instinct of a crab is to seize and pinch anything that comes between the two limbs of one of his big claws. The thing was to find some slight penalty for nipping and see if a crab thus punished would desist from the practice when the penalty was invariably enforced. I first took in hand an Edible Crab, measuring about three inches across the carapace from left to right. He turned out one of my best pupils. I put him in a large shallow bath containing sea water. In the middle was a pie-dish filled with fresh water. I used to put one arm of a forceps between the two limbs of his claw, and every time that he seized it I lifted him and dropped him into the fresh water in the pie-dish, whereupon he would drop the forceps and clamber out. I now give a detailed account of my series of experiments with him.

1. Three times he gripped the forceps angrily and each time was dropped into fresh water. The fourth time he refused the offered forceps.

2. After three or four minutes, he gripped the forceps twice, each time suffering the same penalty. The third time he refused it.

3. After five minutes, he nipped three times. Penalty as usual. The fourth time he refrained from nipping.

4. After six minutes' interval, he seized forceps angrily. The usual fresh water bath. The second time he nipped, but at

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[1] *Loc. cit.*

once relaxed his grip as if suddenly remembering something. On being offered the forceps a third time he nipped, but at once thought better of it.

5. After twelve minutes' interval, he seized the forceps angrily, and so also at the second and third trials; at the fourth, he refused it.

6. After fifteen minutes' interval, he nipped, and there was anger in the nip. A second time he nipped, but after hesitating. The third time he refused.

7. After twenty-five minutes' interval, he seized the forceps venomously, but the second time refused.

8. The next morning, after about twenty hours' interval, he nipped, but at once relaxed. I tried him with various things—a wooden penholder, the leg of another crab—but he always relaxed directly after nipping.

I experimented with another Edible Crab at intervals for six days. He grew more and more gentle. On the last day but one, when I gave him his morning lesson, he at first altogether checked the impulse to grip, then gave way to it once, suffered the penalty, and was wise thereafter. On the last day of these experiments I tried him four times. In the morning he gave three nips only, though I provoked him much. In the afternoon, after some four hours' interval, he nipped, thought better of it, and desisted before I could inflict the penalty.

There are great differences of individual character among crabs. Another Edible Crab on which I experimented proved a perfect shrew. But I forgot to notice the sex, so I will call this unteachable personality "it" to avoid any possible implications. It thrice gripped the forceps, and was each time deposited in fresh water. The third time it stayed in fresh water over five minutes, gripping the forceps. Probably an Edible Crab can stand at least an hour or two of fresh water without fatal results. A shore crab is lively after a fresh water bath of four hours, being used to a brackish fluid. To return to our Edible Crab. After the fourth grip it stopped in fresh water eight minutes, never relaxing its hold. After this I tried the plan of adding a drop or two of methylated spirit to the fresh water. Even then it would stop there two or three minutes, and in some cases have to be pushed out. After twelve baths, producing no amendment, I took to lifting it a few inches and dropping it into a sea-water bath. This was repeated some thirty times. At length it nipped less hard, but perhaps only owing to physical exhaustion. I could not but admire such invincible obstinacy (or was it sheer stupidity ?), and at length returned it to sea water and I hope to happiness.

In two Devil Crabs also (*Portunus puber*) experiment detected a power of learning. No. 1 gripped a wooden penholder again and again, being deposited each time in fresh water. Fresh water he did not seem to mind. He continued for a quarter of an hour to grip the penholder, even when left high and dry without fresh or salt water. I then discarded the penholder and tried a forceps. This he declined to grip—was it too thin ?—but only clashed his two claws together when it was offered him, as if administering two boxes on the ear, right and left simultaneously. Every time that he did this, I suspended him in air and dropped him into water. After six or seven of these experiences he desisted from his clashing. Then I held out to him the carcase of a small shore crab. Nearly twenty times he clashed at this, but at length gave it up, being each time lifted a few inches in air and dropped into his bath. After a twenty minutes' interval I again tried him with a small crab. After about twelve clashes he grew mild. His education proceeded apace. The next day when I gave him his first lesson, three or four clashes at a small dead crab were enough for him. His second lesson produced the desired result more quickly. At his third lesson (five minutes later) he gave three very mild clashes, then settled down to gentleness and self-restraint. He would begin to move his claws as if to "go for" his enemy, then check himself, the higher level of his brain (let us speak of him as if he were not a mere crab) inhibiting the instinctive promptings of the lower.

Another Devil crab became quite mild under similar treatment. It is not only the study of art that

Emollit mores nec sinit esse feros.

Another species of crab, Atele-cyclus heterodon, also showed itself teachable, but I was not able to proceed quite so far with the education of these. The Shore crab does not nip *persistently*, and I did not see my way to training it. This was unfortunate, as I have an idea that its intelligence is, for a crab, of a high order.

We see, then, that even a crab can snub his natural instinct and learn to be a wiser crab. No wonder that in highly-developed vertebrates, such as chickens, we find a power of putting acquired habit in the place of instinct. Some pages back I showed that even an infusorian (see p. 176) was capable of learning by experience, and since it too had to check a natural tendency, I might quote zoothamnium, the crab, the chicken, as representatives of three classes of animals at very different levels of development, that are capable of being taught by the knocks and buffetings that life brings them. For us the business of life is largely the making of habits, a process always involving much snubbing of instinctive impulses or old habits. We cannot be on with the new love until we are off with the old. Not only for men but for the higher animals generally, life consists very largely in the building up of habits, till at last they become almost as automatic as the instincts that we find in the lower strata of life.

We can now draw some general conclusions from the instances given. We find instincts absolutely perfect when they are required only once during the lifetime of the animal, *e.g.* the spinning of a cocoon by a caterpillar. The caterpillar is able to fend for himself from the moment that he emerges from the egg. But whenever there is parental instruction, instincts become weakened. Young chickens just hatched show skill at nothing except pecking. Even their earliest pecking leaves something to be desired. Starting with this one accomplishment they are educated by their mothers till they are fitted to face the world with its many dangers and pitfalls. In such matters as song, nest-building, and flight, though they receive no instruction, birds perfect themselves by practice. Not much is required, the art is almost instinctive. Mammals have a poor instinctive endowment. They learn from their parents and playmates, much from experience, and so solidify and stiffen the habits that their mode of life requires.

Human instincts and instinctive impulses

But what of human instincts? Man's endowment in this respect is very poor and meagre. The instinct to suck the breast is, as with other mammals, ready for use, but very little more. This poverty in respect of instincts means a rich endowment of another kind. For the rule is, poor in instinct, rich in intelligence and power of learning. A bird can build its nest without any instruction, sing its song with none or next to none, fly very fairly well, in some cases, directly it springs from the nest. But birds fall far below the dog or the monkey in intelligence.

Man with his pre-eminent intellectual endowment is far more helpless in infancy than any other animal, and it is long before he emerges from his helplessness. All his infantile movements are made awkwardly, as if with effort. Watch a small child picking a flower. He makes bad shots, unable to estimate its distance from himself, and his muscles are not yet trained to co-operate with one another. Very unlike the young chick who before he is a day old can give a well-aimed businesslike peck. Very unlike that colt who on the fourth day of his life walked ten miles to a show in Edinburgh, and on the evening of the same day walked out again and was quite sprightly at the end of it.[1]

Instead of instincts in the strict sense, man has instinctive impulses, the impulse to play, to imitate, to contend against obstacles (in other words a fighting propensity), to use his right hand when skill is required. Equipped with these impulses he co-ordinates his muscular activities, observes everything around him, makes endless experiments, finds what suits him and what does not, what is pleasant and what is disagreeable.

Monkeys

Some of the instinctive impulses that we consider most human are highly developed in monkeys. Mr Romanes' account of the Brown Capuchin monkey that he and his sister kept as a pet is wonderful reading. "One day he obtained possession of a hearth-brush, one of the kind which has the handle screwed into the brush. He soon found the way to unscrew the handle, and, having done that, he immediately began to try and find out the way to screw it in again. This he in time accomplished. . . . As soon as he had accomplished his wish, he unscrewed it again and then screwed it in again the second time rather more easily than the first, and so on many times."[1] A store of nuts was kept for him locked in a trunk. When the key was given him he tried for two full hours, without ceasing, to unlock the trunk with this key. He had watched the process of unlocking and thought he could do the trick. He found the way to put the key in, but alas! he never succeeded in opening the trunk. The lid had to be pressed down before it would open, and this he had not noticed. Still, he was a great imitator, and he had wonderful perseverance.

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[1] It belonged to Professor Cossar Ewart.

Imitative instinct

How are we to class this imitation? Was it simple imitation only on a par with the endless repetition by a child of a sound heard without any attempt to approximate more closely to it? It seems to be of a rather higher class than this, for there was a definite end in view. But compare this Brown Capuchin with a boy trying to imitate the note of a cuckoo. The cuckoo, let us imagine, tells his name to the woods, and then is silent. The boy imitates the note with moderate success. Keeping the idea of the note in his mind he tries to approximate more and more closely to it. This is something higher than the monkey's merely working the key about in the lock because he has seen other people do it. The boy notes his gradual progress towards success, the poor capuchin merely fumbles with the key in hopes that something will happen.

The impulse to imitate retains some of its power throughout life, though it is not as strong as it is in the boy. The combative spirit, the ambition to excel, the love of praise, often condemned as mere vanity, these motives are strong at all ages. The ambition to excel and to master difficulties often grows stronger during manhood.

Play

I wish in particular to speak of the impulse to play, because so few people see the true meaning and importance of it. All animals that have much intelligence are very fond of play when young. Dogs, cats, lions, tigers, leopards, elephants, monkeys, are good examples, and dogs and monkeys, which often retain much of their love of it in mature life, are, I should say, the most intelligent of mammals lower than man.[1] One factor of genius is the maintenance of youth during the years of manhood. And in like manner the love of play seems to be the measure of the cleverness of mammals generally. Man devotes more years to play than any other mammal, and he is far and away the cleverest. Rabbits are not great at play and are not over-intelligent. I strongly suspect that those lowest of mammals, the duck-billed platypus and the echidna, never play at all or play but very little. At one time I thought that the elephant was an exception to the rule, that intelligence of a high order was found only in animals that devoted much time to play when young. I had never seen an elephant old or young indulging in any antics, and Mr Karl Groos in his book on the play of animals says little about this clever though ponderous beast. But I have it on good authority that much rough-and-tumble play goes on among young elephants. It is to be regretted that they do not keep it up when they have attained their full bulk, but there are many stories, and probably some of them authentic, of their showing a sense of humour. The volcano of fun that was active in their youth is dormant but not quite extinct.

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[1] See *Animal Intelligence*, p. 490.

It goes without saying that animals who educate themselves by playing learn by experience, and so give definite proof of intelligence. They make accidental discoveries. A horse, a donkey, or a dog happens by chance to lift the latch of a gate and remembers the trick of opening it. Some cats were once put in wire cages from which they could get out by lifting a latch, and being left for some time without food, they rampaged round their prisons. At last they accidentally, most of them, did the right thing. Imprisoned again, they remembered the latch and got out quickly. Of learning by the help of chance experiences there is a great deal among mammals and birds, but there is no reason to believe that there are any experiments of a higher kind. There is no deliberate trying of every possible means to an end, still less a thinking out of the best forms of experiment. Even in monkeys the experiments seem of the purely random kind, made without any object in view, in mere play or temper. The thing achieved comes as a surprise. That seems to have been the case even when Mr Romanes' monkey experimented on the hearth-brush.

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[1] The love antics of birds hardly come under the head of play. Birds do not play when young, and they are far behind the cleverer mammals in intelligence.

To return to the subject of play.

Theory of play

It used to be held that play was a mere working off of superfluous energy. A foolish theory, for why should such an abundance of energy exist if it is superfluous? It is impossible to doubt that it has a definite use. To begin with, it teaches the muscles to co-operate with one another. Many movements, jumping for instance, depend on the harmonious working of numbers of muscles. Witness the stiffness extending over the whole body which results from taking a good many jumps after long abstention from that exercise. Secondly, play develops readiness, quickness of decision, nerve-qualities that will be much in request in after years. Play is, therefore, a rehearsal of the grim realities of life. It is remarkable that most boys' games are mimic fights. Rugby football looks very much like the real thing, but the blowing of the whistle stops the battle in a moment and shows that it is but mimicry. Still, if we read accounts of the football of a hundred years back and more, we shall find that it was once almost (sometimes actually) a fight, and that it has only gradually been reduced to its present civilised form.[1] Cricket similarly consists of attack and defence. In chess the principle is the same. Many of the old English games which now live in obscurity will be found to have the same basis. And naturally, because man is a fighting animal, and even in civilised communities success depends on combativeness and persistence. One of the marked differences between boys and girls is the contempt that boys at a very early age feel for dolls. Girls, on the other hand, take the utmost pleasure in playing at what may some day be a reality for them. Children of both sexes delight in a kind of play that is quite unknown

[1] See on this subject Mr Gonne's *Village Community.*

among the lower animals—what is commonly called making believe. There is no need of the elaborate toys that are given to them, for they can make, *e.g.* a sofa cushion, represent anything from a truss of hay to an organ-grinder. In *Punch*, did not some children playing at motor cars make the baby take the part of the smell? Truly, a most important rôle. All this make-believe must develop the intelligence. Louis Stevenson retained much of the spirit of childhood during the years of manhood. Hence the charm of his *Child's Garden of Verse*.

The Formation of Habits

Skill in anything is impossible for a man without much practice, without the formation of a habit. A child is a great experimenter. He tries endless random actions. Some bring unpleasant consequences to the doer himself. Some cause annoyance to mothers and nurses. Others bring the reward of success, for something is achieved. Everything has to be learnt by the human infant. He is the very antipodes of the caterpillar, who is perfect in all (that is, both) his accomplishments, eating and cocoon-making, without any practice. The learning of writing involves great muscular difficulties. The whole body is put into a strained position and the tongue is protruded. At last the hand manages to do its work without troubling any other part of the body. Gradually, for the young human experimenter, actions become more and more automatic. Talking comes with less and less effort; running takes the place of laborious toddling; the right behaviour in the right place comes easily and unconsciously, one kind of behaviour for the drawing-room and another for the play-room. Habits are gradually built up, habits that play the part that instincts play in animals of a lower class. The individual makes and fashions them to suit his own peculiar circumstances. He adjusts himself to his environment, being wonderfully plastic. But he has predispositions. These predispositions help him to steer his course and prevent him from being the mere creature of circumstance, though they are not unbending and tyrannical like the instinct which drives the caterpillar to do what is right for him, and nothing but what is right. In nearly all cases the child appreciates the difference between right and wrong when it is put to him clearly, and decides in favour of the nobler course. But it wants putting to him clearly. Often, in addition, he has special tastes, but these too require developing, and sometimes there is no very strong bias in any particular direction.

Child and man

The human infant, then, starting with some instinctive impulses—to play, to make believe, to imitate, to combat difficulties—and with some predispositions, builds up habits for himself and builds up his own character. Without well-formed habits, automatic or nearly so, it is impossible to do anything that requires skill. Childhood is a time of great clumsiness because it depends so largely on intelligence. All day long a child is exercising his intelligence, making experiments, picking out the actions that pay, that achieve their end, and rejecting those that do not. A man has got over most of this. He has made his selection of the actions that approve themselves to him, has practised them again and again, so that he is far more machine-like than he was when a child. He is much less clumsy no doubt; he has the skill which requires but little thinking, because it is almost automatic. He may be more, may be less intelligent, than he was in childhood. Most men, I think, are less so. At any rate they use their intelligence much less. For a man, life no longer from hour to hour presents difficult problems which he is eager to solve, generally only a few very difficult problems, and these he often decides to consider insoluble. His habits mainly guide him. He shaves, breakfasts, goes to his office, transacts business, dines and talks, very often without having to exercise his intelligence largely or to disturb any deep-rooted habit. It is absolutely necessary for us to make ourselves to a great extent automata. Intelligence is a good thing, but it cannot at a moment's notice give us the skill we want. A man of humble birth cannot, when he acquires wealth, read up a book on the ways of good society and at once, by an effort of intelligence, comport himself like those who have moved in higher circles all their lives. However strong, a man cannot pay his first visit to a gymnasium and at once perform all the feats of balance and turning that are easy to a trained gymnast. A freshman, when he is going through the process of tubbing, thinks rowing an unattainable art. He has to think of some twenty things at the same time. It is only when nearly all the twenty have become automatic that correct style is a possibility for him. The result is, of course, due to intelligence. Nothing else could enable him to pick out the movements which are right and discard the wrong ones. At length intelligence retreats, leaving automatism to take her place, retaining only her hold on certain points, a certain outer fringe of activities which automatism cannot well take under its sway. The proper rôle of intelligence has long been known. "The late learner" is one of the characters of Theophrastus, perhaps not one of his best. But it is worth remembering that he tries to learn to ride and tumbles off and breaks his head. "Late learning" is defined as "the pursuit of exercises for which one is too old." A foundation of habit is required, and habits take long to form.

Automatism and intelligence

We have not yet done with the question of habits. We have seen that such things as drawing-room behaviour and difficult feats of skill cannot be produced at short notice by intelligence. In the same way the brain cannot do much unless it works, very largely, automatically. Take an ordinary and familiar instance. A boy wishes to translate an English sentence into Latin. There is a verb, the Latin for which he is not quite sure of. After reflection he decides on a verb. Then he debates within himself (or mentally tosses up) the question in what mood and tense the said verb should be put. When he has decided on this, the question presents itself: How is the tense to be formed? Now, the last two questions ought to be decided automatically, and the first without much thinking, so that the whole intelligence may be devoted to the question of lucidity and style. The result of the absence of proper automatism is that his intelligence has to wrestle with four separate problems. He tries, of course, to deal with each separately, like a recruit who has to shoulder his rifle by a series of separate movements. But, as a fact, the youthful prose-writer does not keep the several problems distinct. His mind makes an effort to solve them all at once and the result is chaos, and the chaos is often considered a proof of stupidity. As a matter of fact it is often only a proof of an insufficiency of automatic habit. The same phenomenon arises in mathematics, when an attempt is made to solve a problem without a sufficient familiarity with such methods as the multiplication table and others more advanced than that. How could a man speak without hesitation if he had to be perpetually thinking how to use his vocal chords and where to place his tongue in order to form his words correctly? To be fluent he must devote his mind to thinking and nothing else, and the words must come automatically—his brain forming a chain of ideas and his vocal organs, unsupervised, reeling off a corresponding series of words, just as in shooting the hand follows the eye.

All this in praise of automatism! Education does, undoubtedly, consist very largely in the acquisition of good working automatic habits. But if it results in the killing of intelligence, is it a good thing? A man often finds mere habit serve him so well for a number of years, that his intelligence, for want of exercise, grows feeble, and when there is a sudden demand for it, proves wanting. If the mind is to be healthy, it must always be making full use of intellectual habits, but at the same time building up new habits, and, if need be, remodelling old ones. To tie up one's bundle of ideas in youth, and then get no more, is a poor thing. It is to be like those wonderful conversationalists in George Eliot's *Silas Marner*, who assemble at the village inn, and each of them, every Saturday evening, make the same remarks on the same subjects and tell the same stories, like a singer who has only one or two songs in his repertory. The proper relations between formed habits and intelligence may be illustrated by a simile. Our great forest trees have, just within the bark, what is called a cambium layer where growth goes on. New wood is perpetually being formed here, and each year a new solid ring is added to the trunk, while the bark expands to meet new requirements. Thus growth never ceases, and at the same time a solid bulk of timber is built up, strong enough to resist any wind that blows. The Monocotyledonous plants, on the other hand, have a different method of growth. The bark will not expand beyond a certain amount. When new leaves and shoots arise, they send down new bundles of woody material which pack into the limited space. The sugar cane and the bamboo are examples. But this system of growth cannot produce a lordly tree such as the oak or the sequoia. When a man has no cambium layer, when he is a mass of stereotyped habits and has ceased to grow intellectually, his mind is like a bamboo in its strait waistcoat. When young, up to the age of fourteen or so, the young negro is decidedly intelligent. Then he not only ceases to grow in intelligence, but actually becomes duller. This is a very common phenomenon among savage races. There are here and there brilliant exceptions, notably among negroes. But they *are* exceptions. The natives of Australia, when taught by Europeans, can hold their own against boys of European race till they are thirteen or fourteen. Then there is an end of their progress. They have no cambium layer. This cessation of growth, this negroidness, is with them a physiological fact which there is no combating. It is part of their nature, just as the bamboo's limitations are part of its inherent constitution. But many people of European stock, without being constitutionally negroid, allow a voluntary negroidness to settle down upon them—a most lamentable intellectual state.

The Process of Learning

We have now to investigate as well as we can within a small compass, the working of that very complicated machine, the human mind, the machine which attends, remembers, and deals with new impressions from without, rejecting some ideas as inadmissible, and assimilating others.

The function of pleasure

We cannot understand the process of learning and, in particular, the subject of attention—how it originates and how it works—without first understanding the proper function of pleasure. This may seem odd to those who look upon learning and pain as two things indissolubly tied together. The fact is that artificial means are sometimes employed to make unwillingness to learn painful, in order that the effort to learn may become comparatively pleasurable. And thus, even in these cases, there results from the effort a certain satisfaction—a bare quantum, not reducible without loss of the object in view. When, from a sense of duty, we plod with pain and labour through a dull book, we still have a sense of satisfaction due to the thought of duty done. And this satisfaction overpowers our loathing of the drudgery, so that there is a margin of pleasure, or call it satisfaction (sometimes a very narrow margin, narrow almost to the vanishing point), in the reading of the book. If we felt spontaneous pleasure and interest in the reading, of course our grip of the subject would be infinitely greater and the effort required infinitely less. The pleasure, great or small, is due, as Professor Bain well puts it, to heightened nervous energy. Anything that makes us live a keener life gives pleasure. A cup of vile coffee which is abominable to the palate, may yet give pleasure by stimulating the whole system.

Reinstatement of stimulus

Now we can advance a step further. Actions which are accompanied by a feeling of pleasure ("a hedonic consciousness," says the American professor) we tend to repeat. Even bacteria (generally accounted mere vegetables, and wicked ones too, though I myself reckon them as more than half animals), when anything in which they take delight, such as meat gravy, is put near them, swarm towards it. If, on the other hand, a drop of poisonous acid is put among them, there is a stampede. In the same way, when light falls on Euglenæ (see p. 14), they move towards it, to the side of their little tank. What is the result of these movements? They tend to "reinstate" the pleasant and beneficial "stimulus" (an expression I borrow from Professor Mark Baldwin[1]), and, on the other hand, to prevent further contact with a stimulus which is painful and injurious.

Attention

Let us now, regardless of the dramatic unities, transport ourselves suddenly from unicellular to human society. The boy I spoke of as perpetually imitating the cuckoo's note was reinstating the original stimulus, and, at the same time, doing something more. He was keeping the mental picture or idea of the bird's note constantly before him, and trying to approximate to it more and more closely. He was, in fact, attending to the subject in hand, and the reinstatement of the stimulus was helping him to keep his attention. Probably there is the first dim rudiment of attention in the movement of bacteria towards the gravy that they long for, in the movement of Euglenæ towards the light, and the consequent renewal of a pleasurable stimulus. I cannot myself doubt that amphileptus attends closely to the business in hand when he traps his rotifer and laboriously swallows him. A dog waiting at the mouth of a rabbit hole for a rabbit he hopes will soon try to bolt, ejected by a ferret, is an example of a higher kind of attention. The original stimulus—the sight of the ferret setting about his work—is so strong that it is able to bar the way against competing stimuli, such as thorns in the feet and all the petty irritations that flesh is heir to. The essence of complete attention is that it excludes all notice of subjects other than the one on which the mind is fixed. A young disciple of Sandow once told me that when he was apparently looking at the black-board, and giving his attention to his master's exposition of some geometrical problem, he was in reality tightening up his muscles and, in accordance with the Sandow doctrine, thinking hard of each muscle as he contracted it. His master's exposition failed to distract him, so riveted was his mind on other things. We can imagine a man, by an effort of will, mentally isolating himself and studying a philosophical treatise on one of the islands in the middle of Oxford Circus. Close attention of this kind often involves muscular action, such as the stretching of the drum of the ear by two small muscles, the straining of the eyes, the holding of the breath. But it may continue, I believe, without such helps; for instance, when we lie in bed and fix our mind on some tangled subject which we wish to unravel.

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[1] See Professor Mark Baldwin's *Mental Development in the Child and Race*, p. 185.

How does it come about that we can thus isolate ourselves, give our whole mind and energy to one subject, instead of being at the mercy of every chance sensation, every chance object perceptible to any of our senses? We must go back to our definition of pleasure. Pleasure we traced to heightened nerve energy, due to some stimulus. The pleasurable sensation leads the organism to try and reinstate the stimulus, and thus there is produced, probably, a rudiment of attention even in such organisms as bacteria. But what if the nerve energy be not only heightened, but heightened a very great deal by some exceptionally strong stimulus? This may (and does, as we know) lead to such a response that for some time we continue to think of nothing else. Other competing stimuli knock in vain. They are like bullets pattering against the solid walls of a fortress. The dog's excitement when the ferret is put into the hole is altogether beyond what is wanted for the moment, and it continues to wield despotic sway, so that other stimuli go unnoticed. What has been called the excess nerve discharge excludes all other ideas.

Inhibition of other activities

But we wish to understand the mechanism. How is it that this excess discharge of nerve energy is able to bring about a concentration on one subject and the inhibition of all the other activities of the cerebral hemispheres, that region of the brain which is the scene of conscious life? When only reflex actions are concerned, we have an explanation which almost certainly explains the working of the machinery.

A dog's skin is rubbed or his hair pulled in the region of his shoulder, the brain with its controlling power being prevented from working. The irritation produces a reflex action. The dog lifts the hind leg belonging to the same side of the body and scratches the place. But if the hind foot—still on the same side of the body—be rubbed or somehow irritated, then instead of scratching, he raises the hind leg and keeps it raised. What happens is probably this. The afferent nerves from the shoulder and from the hind foot both bring their messages to the spinal cord. Then from two points in the spinal cord proceed two nerve currents, each directed towards the hind leg and tending to set it in motion. These two currents have to travel along a common path, probably (1) along part of the spinal cord, certainly (2) along the motor nerves that set the muscles of the hind leg working. The result is that the currents compete for the possession of the common path, and the result seems to be that the leg is kept lifted, the avoidance of danger being more important than the soothing of an irritation. When the foot is no longer irritated, scratching is resumed. All this was excellently explained by Professor Sherrington[1] in a paper read before the physiological section of the British Association in 1904. The machinery can be illustrated by the telephone. A, who lives at Portsmouth, wishes to talk to B, who lives at Manchester. He must first be hitched on to B at the Exchange Office in London. He finds, however, that someone else is talking to B—it happens to be C, who lives at Dover. The common path is already occupied, and he has to wait. The theory of the common path admirably explains the inhibition of one reflex action by another. When the higher brain is involved, things are not so simple. For instance, an artist is looking at a beautiful sunset. A thrill passes along the optic nerves to the optic lobes of his brain. He remains so rapt that when the harmonies produced by some travelling musicians strike upon his ear, he remains unconscious of them. Here also the explanation may be that the two stimuli have to act along some common path, and, the earlier stimulus having effectively occupied this, No. 2 remains abortive. But it is far more difficult in this case to say where the common path is. I have to leave the fact unexplained that somehow one mental activity can inhibit another or all others completely. Aristotle tells of a man who could not continue to listen to a speech if he heard flute-playing. Perhaps he was able to give his whole attention to the flute in spite of the speech. But there are some people who have difficulty in barring the various avenues of approach to their brains, even when they are giving the best attention they can to the thing of their choice. Such people have little power of learning anything.

Memory

Memory, "the warder of the brain," as Lady Macbeth calls it, is closely allied to attention. Attention keeps an idea continuously in the field of consciousness. Memory recalls it when for the time it has passed out of the field. And the closer the attention we devote to any subject, the more readily is the impression called up again before the mind. Working together, attention and memory do great things. They store in our minds a host of impressions. One idea rings up another. Here is the essence of memory, as I have explained above. The brain consists of a number of different centres, some very closely connected, others only loosely and indirectly. It is only in a complicated brain like that of man that we have memory fully developed. No idea—no mental picture—lives in lonely isolation, on a separate canvas, but each is capable of bringing into view a series of associated pictures. When one idea thus calls up another, memory is at work. Some sight or sound or other sensation revives the impression of a past experience. A dried flower in a book takes us back to a long-forgotten garden that has for us endless associations. Even when we dream, and a jumbled diorama of our waking experiences passes before the mind's eye, it is some impression from without that has fired the train—that has lifted into the region of consciousness the long series of ideas, each in its turn, each to awaken the next in order.

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[1] See *Nature*, September 8, 1904.

Origin of ideas

Does a child begin life with a stock of innate ideas, or is his brain vacant and untenanted? Undoubtedly he starts with certain instinctive impulses and certain predispositions; but, in spite of Wordsworth's noble poem, he brings no actual ideas with him into the world. These he gathers as the days go by. Every day he comes in contact with various influences, with all that goes to make up his environment. Every day he forms ideas or mental pictures and packs them away each in its place in his brain, till before long it is by no means unfurnished. As the process of furnishing proceeds, it is less and less easy for anything more to get admitted. When a new idea knocks at the portals, the ideas that are already in occupation refuse it admittance if it is very much out of harmony with themselves. To change our metaphor, the assemblage of ideas is a club which does not grant the privilege of membership to each chance newcomer. A candidate may be blackballed. Occasionally, however, a most discordant idea does get elected. The life of the whole organism depends on the admission of a new principle utterly

Admittance of new ideas

out of harmony with the old habitués of the club, and then, perhaps, to avoid a worse alternative, the newcomer is admitted, settles down among the old members, and largely modifies them. But sometimes a man will submit to martyrdom rather than allow such an outrage to the ideas that he has already built into his character.

There is, then, a struggle for existence among ideas. New ones present themselves. They may be strangled by others of older and stronger growth, or they may take no denial, make a position for themselves, and squeeze their rivals out of existence. The process is the same as that by which a man learns complicated movements, picking out what approves itself to him and rejecting what does not. The result is the formation of intellectual habits. As in figure skating or in elaborate gymnastic feats, one movement automatically follows another; so ideas become linked together, with the result that they rise before the mind in an ordered sequence. When a man recites a whole play without hesitating for a word, every one considers it a wonderful feat of memory. It is still more wonderful if we consider what goes on in the brain: that the ideas represented by these words are all arranged thus in series, and that each as it rises before the consciousness for the fraction of a second brings into view the next in order, like an interminable series of ninepins, which, instead of knocking down, put, each of them, the next ninepin in an erect position.

A great part of the intellectual work that a human being has to do as his life goes on is to link his ideas together in series on some sound principle. On the way in which he does this depends very largely his intellectual calibre. Some persons with whom punning becomes a disease use mere fortuitous word similarities as a link between ideas that have no real connection. A pun, a very good one or a very bad one, may no doubt be occasionally an excellent thing. But as a mental habit it is an abomination. Other people associate things according to the place in which they have seen them or heard of them. This seems to be an extension of picture memory, the power of looking into a shop window and then carrying away a mental picture of all the

Originality

various things in it. It is no doubt a very valuable power. But, as a rule, the soundest principle on which to link ideas is that of cause and effect. When a new idea is admitted, it is important to find out whether it ought to be closely associated with any one or more of the existing stock. What we speak of as originality is usually the making of new associations between old ideas. Newton connected the familiar falling of things, apples or other, through the air with the circling of the earth round the sun, and the moon round the earth. The cause that drew the apple towards the earth and that kept the moon from flying out of its orbit were one and the same. Malthus saw a limit of subsistence, a limited amount of fertile land, a limit to the supply of food, with its inevitable result, the very hard life of the poor. Darwin, extending the range of this idea, saw a struggle for existence among all organic beings. This extension of old ideas to new fields, the extension of the realm of law to regions hitherto not invaded by science, is what we call originality.

Mental Growth

Physiological development

Intellectual machines

There are two senses in which we may speak of mental growth. It may mean the acquisition and assimilation of new ideas which enable the mind to do better work. It may mean a growth in actual mental power due to physiological development. Growth of this latter kind is independent of the will, and to all of us there must come a time when it will cease, just as to all of us there has come, or will come, a time when we can no longer clear the gates that once seemed easy, and when even small stiles look formidable things. To the least negroid of us this arrest of development must come. But growth of the other kind may still proceed. We may assimilate ideas that may enable us to do intellectual work that would have been impossible without them. An idea is, in fact, a piece of intellectual machinery of which the brain makes use. By means of a number of such machines it achieves thousands of feats that without them would be impossible. In many cases the mastery of one admits us to the use of others, and the mastery of these to the use of others yet again of still greater power and efficiency, and thus a whole vista of possibilities is opened up independently of physiological growth. Let me illustrate by a simile. Imagine two men, one of whom can walk five miles an hour while the other can only walk four. Not so very much difference after all. But imagine further that the power of walking five miles an hour confers the privilege of using a bicycle—a privilege denied to the slower man—and that by its aid he covers ten miles an hour. Still further, let us imagine that a man who can cover ten miles in the hour is permitted to use a motor. This enables him to do his fifty miles an hour. This velocity confers a further privilege upon him. He is permitted now to travel on a flying machine and thinks nothing of a hundred miles in the hour.[1] Let us apply this to intellectual processes, taking things mathematical first. Counting is only possible through the use of an intellectual tape measure on which ten, twenty, thirty, forty, and so on are marked in special figures.[2] When we can count, it is not difficult to add. After addition, subtraction not unnaturally follows with its wonderful plan—a piece of intellectual mechanism—of borrowing ten and carrying one! Multiplication and division are extensions of addition and subtraction. Then knowledge of the four primary rules admits us to such advanced processes as finding the common denominator of fractions, the simplification of fractions and so forth. Arithmetic naturally leads on to algebra. Algebra is a method which is indispensable in most branches of mathematics. So that in mathematics at any rate all the knowledge that we gain can be made the stepping-stone to further knowledge.

In other fields of study the same principle holds, though the stepping-stone process does not come out so clearly. Consider the part played by language. It is clear that words are mental machines. True, ideas can exist without words. But a new word thoroughly mastered often means the mastery of a new idea. Moreover, words are our only means of communicating any ideas beyond the very simplest. We can make it clear by means of signs that we want something to eat, but we cannot by means of signs discuss politics or the probable fortune of China. We must have a certain vocabulary in order to gain further ideas from books or from conversation. Take such words as subjective and objective, socialism, particularism, materialism, idealism. They require and are worth a good deal of study. When once mastered they become valuable mental machines. Indeed all language is so much mental machinery, which helps the mind to think. Without language it is difficult to attain any clearness of thought. Let anyone who doubts this discard the habit, if he has it, of lazily reflecting on things, and make a practice of writing down his ideas, or of discussing them with a friend.

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[1] I have used much the same simile in my *Problems of Evolution.*

[2] I think Mr Benjamin Kidd first pointed this out.

I have dwelt at some length on this question of mental machines because a very able man, no other than Mr Francis Galton, has estimated the intellectual calibre of a senior wrangler and the "wooden spoon" of the same year by the number of marks obtained. Why, the senior wrangler was able to multiply his mathematical powers many times by the use of machinery from which the "wooden spoon," unless he was very different from most of the men who win that title, was debarred through the poverty of his endowment. Thus the natural gulf between the two was made miles wider. It is a discouraging thought this, that there are many mental implements and machines that many of us will never be able to use. On the other hand, we may find comfort in this, that when we reach our physiological limit and can never hope for any further gain of actual intellectual power, we may still press into our service some new idea, some new method that will quicken our intellectual processes. As the loan of a bicycle to a wayfarer, is the acquisition of some better method, some better system, to the man who is trying to make intellectual headway.

Summary

I will now pass briefly in review the ground we have traversed in this short study of different classes of minds. Starting with the simplest forms of animal life, I have shown reason to believe that even the Amœba and the Infusorians have some rudiment of intelligence. Zoothamnium, one of the latter, profits by experience, in fact learns. Higher in the scale we are able to divide actions into three classes—reflex, instinctive, intelligent. But the reflex actions may be accompanied by a dim consciousness somewhere in the spinal cord, and may be really instinctive, or even intelligent. In man we find what appears an immeasurable advance beyond the intellectual high-water mark of other animals. Instead of instincts, he has instinctive impulses that set him to work to learn. He has a wonderful power of attention, so that he can devote all the energy of his very complex brain to one subject. One idea rings up another, so that the wave of his consciousness is a marvellous series of mental pictures. Probably there is no great gulf between men of the lowest races and Mr Romanes' monkey. But without language, without an interchange of ideas, without teaching, the mind can do little. Language and writing put at our service the great accumulated store of human discovery and wisdom. We stand at the top of the pile and try (or do not try) to add something to it, so that our successors may begin at a slightly higher level than ourselves. Language and writing have made possible for the human brain its greatest achievements. But we must not forget that there are large differences in intellectual endowments, that such men as Newton and his few peers stand high above the generality. It is not only that they have been heirs, like other men of civilised races, to a vast accumulation of knowledge, to language, and other means of multiplying many times the power of the mind. Quite apart from such helps, Nature bestowed on them stupendous intellects. And yet it would seem that the long course of evolution has added no absolutely new power. In the lowest organisms we have protoplasm with little of specialisation, with nothing of complication. The nerve and brain power is diffused throughout the one cell, which carries on all the activities of life. In the human brain we find specialisation and complication carried to the highest point. It is an intricate complex of ganglia, with only brain and nerve work to do. Beyond a doubt, it is the most wonderful thing in nature. In itself, and in its achievements, it is so wonderful that it is difficult to believe in its humble origin. Still, the raw material for this most glorious of structures is to be found in the one-celled micro-organisms.

"What a piece of work is a man! How noble in reason! How infinite in faculty! In form and moving how express and admirable! In action how like an angel! In apprehension how like a god!" So said Hamlet. And who will not agree with him? And yet, with all his brain-power, man is akin to the micro-organisms.

A more difficult problem

Here is a very definite verdict; up to a certain point a very clear and definite one. Still, it will convey widely different meanings to different people. Some will think of the micro-organisms as sharing the greatness of man. Others will see in it rather the degradation of man than the ennobling of the lower ranks. Fresh from laboratory experiments, they will say that man, like the unicellular organisms, gives to every stimulus from without an inevitable response. His environment plays upon him as a musician plays upon an instrument, and all the actions which seem to depend upon the will are according to this view only disguised reflexes, disguised by the complications of the brain, by the conflict between contending motives (contending stimuli from without), and by the accompaniment of consciousness. When Cranmer held his right hand in the flame he was only doing, they would say, what he could not help doing, being what he was, just as the heliotropic Euglena cannot help moving towards the light. This great problem I cannot at present discuss. My present purpose is only to show that the minds of the unicellular organisms and of man work in essentially the same way. The high and the low, the complex and the simple, must stand or fall together. If an Infusorian is but an instrument played on by the environment, man must be set down equally as an instrument that is played upon, though a very splendid one. But though the laboratory men abolish will (indeed quite apart from them and their experiments free will in the old sense is unthinkable), yet there remains something as yet unexplained. There is the wave of consciousness that never ceases its onward movement. Somehow, on a principle we cannot as yet understand, it runs parallel, so to speak, to molecular changes in the nerves. Somehow (a thing still more inexplicable) an idea seems to affect the nerves, affect the health, change the condition of the whole man. What is ethereal, incorporeal, seems to affect the body. Mind seems to influence matter. But let us suppose that this is not so. Let us admit, for the sake of argument, that consciousness is a mere by-product of nerve energy, that it is due to the movements of molecules in brain and nerves, and that, as Huxley put it, it is the mere whistle of the steam engine. Yet, how are we to explain such whistling as this? How can a material whistle produce such music? In fact the movements of molecules and consciousness seem things so different in kind that it is difficult to conceive of either producing the other. Here, then, is something that, so far, has not yielded to the attacks of the materialist. To be honest, however, it is difficult to see how the explanation, whatever it may be, can give us freewill. We should remain automata. Yet one cannot help cherishing some poor shred of hope that we may be free in some true sense. And here, too, is a consolatory fact: for practical purposes what is wanted is not free will, but a working belief in it. When the time for decision and for action comes, a man must feel that he is free to choose or he is lost. And this working belief in freewill, even though the thing itself be proved to be a phantom and an illusion, is the inalienable property of every healthy man.

Chapter VIII

THE STRUGGLE FOR EXISTENCE

Proof that there is a struggle

EVERYONE agrees that there is a struggle for existence going on throughout the organic world. It is easy to show that if the natural increase of any species were not somehow checked, it would soon people all the seas, all the rivers, all the land. In a hard-roe herring every granule of the roe is an egg, and an egg is a potential herring. What if all these potentialities became actualities, became, in fact, herrings and grew to maturity? There would soon be no room for anything but herrings in the ocean. Take the gannet or solan goose which lays only one egg. Yet, if gannets met with no accidents, they would before long swarm everywhere as, in the time of that particular plague, frogs swarmed in Egypt. Darwin selected for his *à priori* proof of the struggle for existence the very slow-breeding elephant, and he showed that if their numbers were not somehow kept down, the descendants of one pair would, before 750 years had passed, amount to close upon 19 millions. This rapid increase means competition, a competition in which survival is the prize of success, and extinction the penalty of failure. In fact there is not a species of animals or plants but depends on its merits for its existence, and is fighting for dear life against cold and heat, rain and drought, disease and, perhaps its most formidable foes, other species that compete with it or prey upon it. This is accepted on all hands now as established fact. But if the struggle is so universal, it is odd that we see so very little of it. Peace and quiet is the keynote of an English country scene. It is true that there is war to the knife between the farmer and the gardener on the one hand and the weeds on the other. But the farmer and gardener seem not

Little ocular evidence

to be part of nature. They interpose and interfere from outside. If we go into a wood, the great trees have a look of serene calm, the calm of the gods of Epicurus who were above all quarrelling and bickering. When we come to look at the animals we seldom see anything of war. The rabbits are quietly feeding, the stoats are seldom in evidence though they exist. Man occasionally appears on the scene to reduce the numbers of both rabbits and stoats. The small birds have apparently few troubles. Even where sparrowhawks and magpies are still plentiful, we seldom find them actually at work. We may go to countries such as Spain, where birds of prey are still common. Yet we shall not often see them catch and kill. Occasionally, perhaps, we may see an Imperial eagle make away with a red-legged partridge, or a marsh harrier seize a lizard or a small bird. We may possibly descry a Snake eagle rising in air with a serpent dangling from his talons. An ornithologist when he does see these things is delighted, for he does not see them very often. Nature is rather like ancient Greek Tragedy. To a great extent she keeps the deeds of blood out of sight. But it must not be forgotten that in nature, as in Greek Tragedy, deeds of blood are actually perpetrated. Still the world is not a shambles with slaughter and nothing but slaughter going on from morn till noon, from noon till dewy eve. Nor has every live creature a hairbreadth escape, supposing that he is lucky enough not to be killed, every minute of the day. The lives of wild animals recall the romances of Walter Scott rather than those of Dumas or Mr Stanley Weyman. As Mr Chesterton has pointed out, Scott's heroes linger over their meals; they take delight in bombast, often very high-class bombast. The novel of the modern school is often an uninterrupted succession of blood-curdling incidents which leave, however, hardly time for our blood to curdle at the thought of one of them before we are plunged into another. But Scott's heroes have on occasion to win their lives, and it is so, no less, with wild animals and even with plants. We see, as a rule, only those who are victorious as yet, see them enjoying life serenely, all past dangers forgotten and the dangers to come throwing no shadow over the brightness of the present. The human race has almost the monopoly of the misery of the world.

Struggle at crises only

The fact is that for animals and for plants the struggle comes only occasionally. There are crises that carry off victims by the hundred and the thousand, and there are quiet interspaces. And these quiet interspaces make up the greater part of the lives both of animals and plants. But whether they survive and leave descendants or survive only as fossils (or not even as fossils) depends on their ability to meet the recurrent crises.

These crises come in the form of severe cold, or drought, or a new disease, or some geographical change causing an influx of new forms of life into old-fashioned regions, or merely in a sudden attack from a fierce enemy, tiger, wolf, eagle, or whatever it may be. A severe winter plays havoc among birds. The thrush cannot dig up the worms when the ground is hard as iron, and he cannot keep up his temperature when he has no fuel for his furnace. Youth is a time of crisis for all, even if nothing exceptional is happening. For though each pair of most species produces more than two young, we find no increase in numbers when next spring comes round. And it is not, as a rule, the mature animals who have succumbed to the perils of the winter. It is the young and inexperienced. How few gannets, comparatively, we see in immature plumage. And yet they are not grown up till they reach their fifth or perhaps their sixth year. This points to a great death-rate, though they lay only one egg. The larger gulls are not mature till their third year, and till then their youth is shown by their brown plumage. In autumn we see huge numbers of these brown gulls. In spring the mature birds preponderate very largely, so that the winter time must have seen many tragedies. Dr E. A. Wilson estimates that among the great Antarctic penguins, the Emperors, seventy-seven per cent. of those hatched out perish while they are still in their down feathers. This is his estimate for the one penguin "rookery" about which he was able to make statistics. The circumstances under which these birds are brought into the world are very extraordinary. There being nothing to make a nest of, the mother bird places her feet beneath her one egg, and bends over it, shielding it from the weather by means of a great amount of loose-hanging skin, the special endowment of the Emperor penguin, which almost envelops the egg. The thermometer is many degrees below zero, and incubation lasts for six winter weeks, during part of which the sun does not even rise above the horizon. The cock bird relieves his mate at intervals, is on duty for a spell. Even so, it must be very trying work, making great demands on the vitality of the birds. But we must be careful not to imagine that the Emperor penguin suffers as we should if we stood for hours or days barefooted on ice. His feet are covered with a horny epidermis, and the ice, Dr Wilson tells me, does not thaw beneath them. Apparently they are hardly sensitive to cold, and have little blood in them, the toes being moved, as in other birds, through the agency of tendons, by muscles higher up on the leg. But allowing for this, the six weeks' incubation is a wonderful thing. When at last the time is over and the young bird emerges, the parents go to catch fish for him, and he seems to be left to the care—officious but clumsy—of any leisured birds that are about, birds, apparently, that are too young to mate. The poor infant is often nursed into many pieces, so eager are they to help. The wonder is that the death-rate among infant Emperor penguins is only some seventy-seven per cent. The longevity among those that attain maturity must be very great, or these Antarctic "rookeries" would die out. But there is no reason, I think, to suppose that the "rookery" investigated by Dr Wilson had an exceptionally high death-rate. Apparently the birds have few enemies—there is one species of seal that preys upon them—and owing to this paucity of enemies they can afford to sacrifice a great many of their nestlings. The stormy time of infancy past, they find themselves in fairly calm water.

For all species of animals the struggle for existence may become a stern reality at any time. A new disease may make its appearance. An epidemic may depopulate the grouse moors. Smallpox, consumption, or measles may swoop down on Pacific islanders. Quite apart from epidemics, it is probable that disease kills more wild animals than most people imagine. Even a small ailment must be fatal, and so quickly fatal that we are not likely to notice its victims, especially as the poor sufferers would naturally hide themselves away. Among domestic animals it is frequent and visible enough. Even pigs get rheumatism or something not unlike it, pigeons get bad throats, highly bred horses are privileged to have many diseases.

Among men, disease plays an important rôle before civilisation has advanced far. An examination of the bones of an ancient Viking who was buried in his ship shows that he suffered from rheumatism. The Indians in Newfoundland contrived a kind of Turkish bath, for chiefs, it is believed, who had their ailments like the modern great. As soon as the sufferers are able to lie up and have their food brought to them, disease makes itself visible. Among wild animals, who persecute the weak instead of nursing them, it is nipped in the bud.

Persecution of the weak by their companions

This persecution of the weak by their near relations is the most unpleasant phenomenon to which the struggle for existence gives rise. No sooner does a poor old hen get sickly than her more vigorous companions—her own daughters among them—peck her and tease her and hasten her end. No sooner does a cow show signs of weakness than she is persecuted by other members of the herd, though, as Mr Hudson maintains in his *Naturalist in La Plata*, only the less noble spirits join in the persecution. The lords of the herd seldom take part in it. In time of dearth, rats become cannibals, a small pack set upon a weakly one who is very speedily devoured.

Swans, when the nesting season comes round, will not tolerate the presence of their young of the previous year on their pond. A pair of golden eagles will not allow another pair within the large circle which they claim as their own domain. There is a great amount of bullying among pigeons, and it is said that a weak bird is sometimes worried to death by a stronger, but I have never seen this. In addition to the widespread tendency to

Fights between males

pester and plague the weak, there are the nobler battles between the males at the time of courting. Even in species where pairing is the rule, there is often a great deal of fighting. But it is among the polygamous, such as the antelopes, the deer, the jungle fowl, that the fights are most desperate, most essentially part of a system. This intolerance of weakness that is so general among animals really reduces the amount of suffering. There are no lingering maladies. Individuals in whom disease appears early in life are not likely to leave any progeny among them. Among civilised men disease is developed till it assumes terrible proportions. About 48 per cent. of the population in England die before the age of 25, and disease accounts for most of the deaths.

To return to wild animals.

Hunter and hunted

Besides the domestic fights and persecutions within the species there are attacks from without, the bird of prey swooping on its victim, small mammal or bird or reptile. There are the carnivora that pursue the ruminants. The deer and the antelopes must outpace or be too alert for the lions, the cheetahs, and others, or pay the penalty with their lives. Sometimes the balance of nature is upset, and the match is no longer a fair one between pursuer and pursued. It is not a fight but a massacre. This happens when some region has long been shut off from the great competitive world. The animals thus secluded have their own wars, but their weapons and all their methods are out of date. Then some new land connection is formed. Some narrow strait that served to isolate these old-world forms of life is bridged over, the land rises and there is an isthmus. Then the fiercest and most formidable products of the competitive system of a continent, equipped with all the most recent developments of talon and tusk, swarm into the sleepy isolated land and massacre its helpless denizens. It is like a war between civilised men and savages, magazine rifles on one side and on the other bows and arrows or assegais. There was a wonderful example of this when South America, which had formerly been an island, a natural museum full of ancient forms of life, became connected with North America. In what is called the Santa Cruz period,

South America

because all its most typical animals have been discovered as fossils at Santa Cruz in Patagonia, the fauna of South America was such as could be found nowhere else. North America must at the time have been separated from the South by a strait of sea, for its fauna was very different. The southern half of what is now the American continent had a wonderful collection of animals found there and not elsewhere. There were gigantic Edentates, so-called because they seldom have either incisor or canine teeth. Of these Edentates the ground sloths were the most gigantic. The Megalothera was as big as an elephant. Remains of a Glyptodon, twelve feet in length, have been found. How these huge dimensions dwarf those of any existing Edentates, of the armadillos, the near relatives of the Glyptodons! (fig. 92, p. 222).

There was a long-necked, three-toed Ungulate—Macrauchenia—as large as a camel. But perhaps the strangest of all the strange collection were the Prototheres, the feet of one species of which mimic those of horses, for each bears only one single toe. And yet their general anatomy shows that these Prototheres are by no means horses. Besides these wonderful mammals there were no less wonderful birds. The Siriema had a skull as big as that of a horse. In brief, there were living in South America, during the Santa Cruz period, huge Edentates, very strange Ungulates, monkeys, broad-nosed and with thirty-six teeth, bats, rodents, marsupials, besides birds of a very peculiar type.

The Marsupials resemble those of Australia, suggesting a land connection formerly existing with the Australasian region. Then, the strange hoofed animals have their nearest allies in the little hyrax, the coney of the Bible, whose teeth are those of a rabbit while its feet suggest the horse and its allies. The hyrax is found only in the Old World in Syria and Africa and, as a fossil, in Europe. This suggests an ancient land connection between South America and Africa.

Huge as many of the animals of the Santa Cruz period were, they were not formidable in attack and not very strong in defence. None of the Ungulates had horns nor were their teeth well adapted for fighting. There were, it is true, carnivorous Marsupials, allied to the striped wolf or Thylacine of Australia,

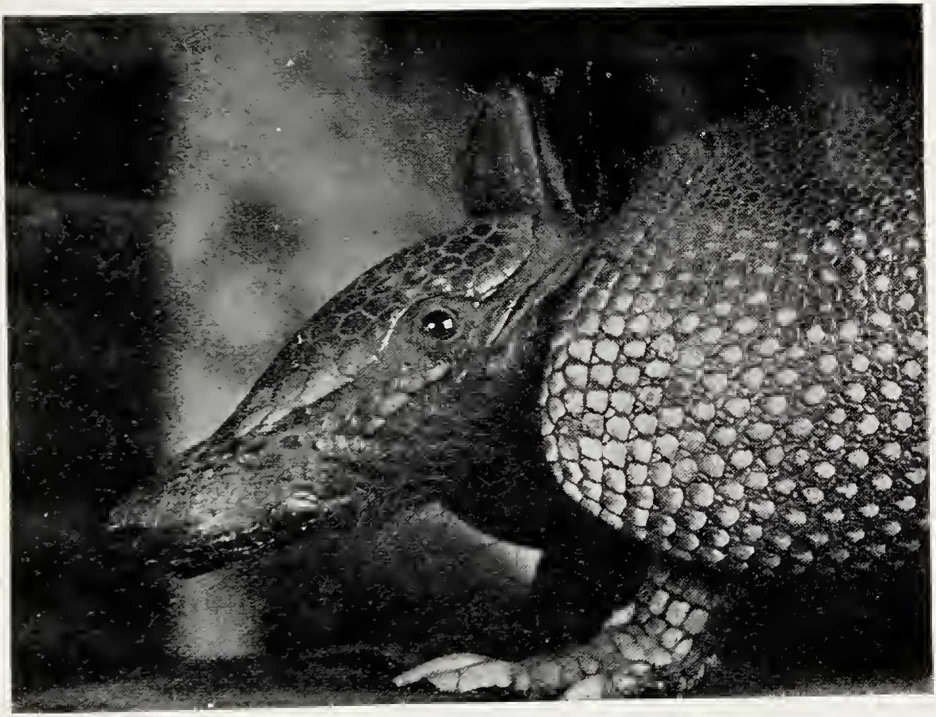

FIG. 92.—Nine-banded Armadillo, just over half the actual length.

Facing p. 222

but in comparison with the great Carnivora, the lion and the tiger, or even the puma and jaguar, they had little fighting power.

At a later date, in what is called the Pampean period, this secluded land, where all these peculiar forms had been developed, was invaded and more up-to-date types from North America swarmed in. The cat tribe were represented by the puma and the jaguar. There were sabre-toothed tigers, bears, fox-like dogs, mastodons, tapirs, horses, deer, peccaries, huanacos, rats, mice, perhaps opossums. The descendants of these invaders are still living or are found as fossils in the débris of the Andes that lies spread over the Pampas region. The heavy, slow-moving, ill-armed South American animals were poor antagonists for so formidable an invading host. Many of them disappeared during the interval between the Santa Cruz and the Pampas periods, and it was during this interval that the invasion took place. But it was during the Pampas period, *i.e.* after the invasion, that the Glyptodons, ground sloths, and Macrauchenias attained their greatest development. Hence a doubt has arisen in the minds of some high authorities as to whether the old fauna was really exterminated by the new, or whether the old did not owe its destruction to some other cause, for instance to the disappearance of the forests that once covered the Pampas region.[1] But the disappearance of the forests may itself have been due to the devouring of young seedling trees by invading rodents. Mr Russel Wallace, in his *Darwinism*, quotes Mr Edwin Clark,[2] who says that during periods of drought the cattle and the rodents tear up even the wiry roots of the Pampas grass. Trees will flourish well enough when protected. Here, then, is a desperate struggle between plants and animals. But the question is: Do these rodents represent the ancient South American races or are they invaders? Among them is the Biscacha, one of the old inhabitants, I believe, much like a gigantic rabbit. But there is also the rat, one of the invaders, and he sticks at nothing when hunger goads him.[1] At any rate we may make this rather vague and guarded statement: The balance of nature was upset by the invasion from the north, and when such an upset occurs there may be far-reaching consequences beyond all calculation. Certainly I cannot picture in my mind's eye the jaguars, the pumas, the sabre-toothed tigers living among the unwieldy Ground Sloths, Glyptodons, Macrauchenias, and believe that the fierce, rapacious invaders did not play havoc among the helpless owners of the soil. Some species, no doubt, held out longer than others. Some underwent further evolution and grew to greater bulk. Perhaps their large size defended them for a time. At any rate they eventually passed away and left the newcomers in possession of the field.

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[1] Mr R. Lydekker inclines to this view. See his excellent article in the *Quarterly Review*, January-April 1903.

[2] See *Darwinism*, p. 23, and Mr Clark's letters in *Nature*, vol. xxxi. pp. 263 and 339. Mr Clark's book, *A Visit to S. America* (1878), is very interesting reading.

New Zealand and Australia

On a small scale things similar to this invasion of South America have happened in recent times. New Zealand has been invaded by European plants and animals, importations that were to have been blessings but which have proved to be curses. Rabbits multiplied till they devoured everything. Cats and ferrets were then naturalised in the hope that they would keep down the rabbits. But the ferrets preferred to live on the non-flying native birds. Preserves have been established to save the Kiwis and other forms of life, the destruction of which would be a calamity as great and as irreparable as the destruction of Raphael's "Madonna." But when once the balance of nature has been upset it is very hard to re-establish an equilibrium. Starlings have been imported into Australia to eat the fruit-destroying caterpillars, but they prefer to eat the fruit, and have proved a greater plague than that which they were intended to cure. Not only do these bold adaptive birds devour fruit unconscionably, but they turn kingfishers, tree-swallows, tree-creepers out of their nests. Thus the struggle for existence goes on, and when men intervene and alter the conditions, the fight is often a very unequal one.

Associations for mutual defence

The struggle is not always between individuals, whether of the same or of different species, but sometimes a troop combine and beat off an enemy. Small birds mob a hawk. Rooks, gulls, gannets, and other kinds of sea birds protect themselves from birds of prey (and those of them that nest on the ground, from predatory mammals) by forming large associations among which no bird of prey, not even the boldest, would venture. Even the heron finds safety in numbers. Alone he cannot protect himself from the peregrine. When one bird catches sight of the common enemy he gives the warning cry, and at once all are on the alert. When the curlew's alarum is heard on the shore, up get not only the curlews, but the red-shanks, the green-shanks, the ringed plover, the dunlin, and most of the rest. And so with herds of cattle and flocks of sheep. The musk oxen form into a knot and face their enemies, the wolves or the sportsman —though it is of no avail to face him—calmly and stolidly. Among insects we find associations most elaborately developed. The bee works herself to death for the good of the hive. For the good of the hive, hundreds of drones are stung to death. Even young queens are slaughtered before they emerge from their cells by the new queen just born, if it happens that the hive wants no more royalties at the time. If more are likely to be wanted, the workers intervene and put a check upon the murderous instincts of their sovereign. The individual counts for nothing. The association is everything, and there is a spirit of the hive, as Maeterlinck calls it, which drives each individual worker to sacrifice herself (and the drones) for the common good. All the life of the hive has been described by Maeterlinck in his *Life of the Bee*, a book of thrilling interest, as full of life as the hive itself.

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[1] I have known a rat gnaw away the wood of a racquet in order to get at the gut that was protected by it.

As a rule, animal sociability does not lead to complete friendliness among the members of animal associations. The bickering among gannets is unceasing when their nests almost touch one another on the cliffs. No sooner is the owner gone from her nest than a neighbour steals a bit of dry seaweed from it. But often the owner when she returns recovers it with interest. Gulls, when gathering worms and other delicacies on the shore, are continually wrangling, and bickerings occur between individuals in herds of cattle and goats. But such things do not disgrace a hive of bees. The drones or the young queens are offered as a sacrifice to the spirit of the hive. They are not the victims of an outburst of bad temper.

Prince Kropotkin's book on *Mutual Help among Animals and Men* is interesting and amusing. He reads into the characters of animals all his own kindliness and humanity. They are all helping one another. He can hardly see any signs of the struggle for existence. He does not realise that they form their combinations because they have to hold their own in war or perish, and because to fight as an isolated individual means death. Hence all these combinations are to him evidences of benevolence rather than of war. He is very sorry for the poor lions and tigers. They have adopted a wrong policy, in not forming herds to aid one another. Hence their small numbers compared with the vast hosts of ruminants. But, we might urge, though they do not form associations for mutual defence, these savage carnivora are the cause that the ruminants co-operate and aid one another. If there were no enemies, what need of co-operation? As to their small numbers, that comes from the nature of their food. Antelopes are much more scarce than grass and much more difficult to come by.

The sphere where benevolence best shows itself among animals is in their care for their young. They feed them and tend them so well that they are all vigour and vitality. As soon as they are grown up, they have to fend for themselves. They have a splendid start in life. If, after this, they cannot hold their own, they must go to the wall. Compared with this system, how cruel is that which prevails among the poorest classes in our towns! They are miserably fed when young, so that they never develop the strength which is potentially theirs at birth, and never attain to the exuberant vitality that should characterise the whole world of living things.

Let us return to the question of associations for mutual defence. Among men we find them as far as we can go back in history. There is the family, the smallest and most important association, and there is the tribe and the village community. There are trading guilds, leagues of trading towns, the Hanseatic league being the great example, and finally the nation. All these associations derive their vigour from the fact that there are enemies against whom they must hold their own. War is an essential part of the life of tribes. Village communities, when they throve best, used frequently to make war upon one another, seize tracts of land from rivals and hold them by armed force. At some periods they have derived their strength and cohesion from the necessity of resisting the demands of the tax-gatherer. When the central government grew strong, so that wars between little subordinate groups were impossible and the tax-collector was backed by an irresistible police, then the village communities dwindled, and the days of individualism, as we call it, came in, the period when each man stands as an individual. This would be impossible unless the State, the central government, were very strong and its police ubiquitous. So strong is it that even the family, that ancient association, which we look upon as destined to continue as long as the human race endures, is much weakened. The State takes the children and educates them, and some people, not the wisest of mankind, even urge that the State should feed them. We see no struggle between groups till we cast our eyes on the larger associations. Even among nations it seldom breaks out in the form of war. Still there is an unceasing preparation for war, an unceasing investigation of the armour of rival nations to see if a weak spot can be found. In these days of individualism the nation remains firmly welded together, for it may have at any moment to contend for dear life. The spirit of co-operation is weak in the smaller associations, in our towns, for instance, because for them, as units, war is out of the question. Even such names as Birmingham, Manchester, Glasgow awaken only a moonlight patriotism. The real, living patriotism is that which we feel for our country, since our country still has enemies and may have to fight for existence. Were it not so, we might have a modern reproduction of the Saxon heptarchy.

We see, then, that there is a real struggle for existence (1) against climatic conditions, (2) a struggle between individuals, (3) between groups. It is mainly because there is war or the possibility of war that man and the lower animals form associations.

Plants and the struggle for existence

Is there any struggle among plants? It is no less real than among animals, though generally even less apparent. Sometimes we seem actually to see it. For instance, on those bare heaps of stones and débris that glaciers deposit in the valleys. Various hardy plants get a footing there, make something of a soil, then are ousted by others that have the advantage when once a soil has been formed for them. The same thing may be seen going on at Dungeness. There are square miles of beach, of wave-worn flints, now raised a little above the sea level. Elder bushes, generally sheltered by hollies, blackthorns, so flattened down that their utmost height is hardly one foot, broom bushes and a few tough grasses—these are among the plant pioneers found there. If you try to pull up a small broom bush, you find that it sends down an enormously long tap root. Indeed it must do so, for the flints go down a good many feet and the plant wants soil. It must have been a critical time when the seed was germinating and sending out a root to look for something to grow in. It is a wonder that the broom with its small seed could afford to wait long enough. Some of the broom bushes are overgrown by the dodder, a little parasitic plant belonging to the convolvulus family. And sometimes the parasite kills the broom, its host. At Dungeness it is so (or was so when I was there some years ago), and I think this shows that life is not very easy there for the broom. Just a little further inland a thin surface soil has been formed over the flints and good meadow grass is flourishing. The pioneer plants are no more. They have done their work and others are reaping the benefit.

> "Thus ye make soil not for yourselves, O broom bushes."

Mr Moore, in his *Tanganyika Problem*, gives a very interesting account of the same thing in Africa.[1] A lake retreats and leaves flats of bare, parched sands. In this inhospitable soil spring up euphorbias (or spurges). Spurges there grow big, and after a time they become small trees, able to shelter other plants for which they have prepared the soil. And so in these "Park Lands" we find clumps of trees, in some of which still survive some of the euphorbias that were the original colonists. In others, having done their pioneering work, they have completely disappeared.

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[1] P. 113.

In Denmark, birches formerly covered the forest land, but there came an invasion of beeches. The invaders had this advantage, that they could grow under the birches, whereas the birches could not grow under them. The beech shuts out the light, whereas the birch does not. Nothing but the holly grows well under the beech. Being an evergreen, it is able to make use of the light when the beech is leafless. The birch, then, in Denmark, is being ousted by the beech, and is being driven to situations where the soil is too poor for the invader.

Mr Wallace, in his *Tropical Nature*, gives a wonderful account of tropical forests and the struggle there. There are the great trees, the monarchs of the forest, and below them trees of smaller growth that between them effectually shut out the light. Hence, at ordinary times, the seeds of the great monarchs have no chance to grow. But when some big tree falls and carries with it numbers of the smaller fry, then there is an opportunity, a skylight has been made, and all the trees, dwarfs or giants, strive to annex the ground beneath by scattering their seed there. It does not do to fail when a chance such as this occurs.

It must be owned that there are trees which thrive, though they blossom but seldom. The Talipot palm in Ceylon blossoms only once in a life-time (in its sixtieth year or thereabouts, it is said), then dies. And yet it thrives. It seems that it does not grow in thick forests where there is a struggle for light, but that it competes mainly with smaller plants for the soil. Its seed begins to germinate before it falls, and so it seems to get the start of rival plants.

So much for the wars within the vegetable world. Of the wars of plants against animals I shall speak later on (see p. 254).

General results

We see, then, that both among plants and animals the struggle for existence comes at crises, that there are peaceful interspaces of much longer duration than the times of conflict. During these interspaces, all living organisms have a superabundance of vitality. They are equipped so as to be able to face a crisis. In the piping times of peace they have a large surplus of vitality. In birds, this shows itself in song and in gyrations in the air for the mere pleasure of singing and flying. Song and flight they need for very definite purposes. But, having got these powers, they take a delight in their exercise quite apart from any end to be gained. Wild animals have a life of exuberant happiness.

Chapter IX

NATURAL SELECTION

Physical vigour

WHAT is the result of the struggle for existence? What good, if any, results from the elimination of the majority of each generation as it comes on in its turn? Beyond all dispute it produces physical vigour. All species are adapted to the conditions under which they live, and the conditions are hard. Even in regions like Australia, where ancient forms of life have been secluded, and have not kept pace in evolution with Continental species, yet there is no want of physical vigour. That wonderful survival, that living fossil, the Duck-billed Platypus, is full of vitality though his temperature is a little below 77° F. Much of the enormous amount of elimination that goes on is no doubt undiscriminating, especially among those animals who produce an enormous number of eggs and take no care of their young. Even in the highest classes mere accident accounts for many deaths. And yet in the long-run, rough as the system is, merit is rewarded. It is only where the stringency of Natural Selection is reduced that we find a decline in physique. Our domesticated animals have not the health of the wild stocks. The zebra's health is as rude and strong as his temper. The highly bred horse, compared with him, is a hothouse plant, and this regrettable fact we must attribute largely to the softening of the environment. Wild animals are selected for certain qualities that they possess in combination with constitutional vigour. The breeder often selects for the points he requires without regard to the question of health.

Heredity and Variation

But physical vigour is by no means the only result traceable to the struggle for existence. To make things clear, let us put the formula of the theory of Natural Selection as it is usually given. The principle of heredity brings it about that in all classes of animals and plants the offspring are like, but not exactly like, the parent forms from which they have sprung. Among these various forms, those which are best suited to the conditions under which they have to live, survive and leave descendants, whereas the less fitted die the death and leave no descendants. After quoting this formula, high authorities will, as a rule, go on to say that it is difficult to account for the variations which form the material on which Natural Selection has to work. They are there, they say, and so we may take them for granted and, with Darwin, describe them as spontaneous. But I am unable to accept this view of the question. Let us take any unicellular organism, some Infusorian, and see what happens. It multiplies by fission, by continual dividing. At last division can proceed no further. Exhaustion results and the infusorian conjugates or fuses with another of its species, and after a pause fission goes on merrily once more. This process of fission is at work throughout the organic world. Now, if we take any small thing, say a piece of paper or a wooden match, and try to cut it into two equal halves, we shall very nearly succeed, no doubt. But the two resultant halves will not be exactly equal, even if we make the most accurate measurements we can. The smaller the object, the more difficult is the task, and partly for this reason that a very slight inequality counts for a great deal when the whole thing is so small. What must happen, then, when a minute cell divides? Clearly the two halves cannot be exactly equal, and in this inevitable inequality we have the prime cause, I believe, of the variations that arise in the most stable of species. Moreover, fission is not always a simple affair. Often it is preceded by elaborate changes in the nucleus; the bands (in some species, granules) of protoplasm, in which the life of the nucleus seems to reside, go through a series of complicated manœuvres. The object of this may be to bring about an equal allotment of the essential constituents to the two halves, but it would be a miracle if it succeeded absolutely. The loss of vitality that results from a long-continued series of fissions would seem to result from this inequality. Conjugation (or amphimixis, as

Weismann has called it) sets things right, the two cells that fuse having between them all the elements that are essential to the life of the organism. It is popularly supposed that amphimixis plays a very different part from this—that it is the prime cause of variations. Every breeder of cattle or sheep would stoutly maintain this. Nevertheless there is not much evidence that justifies us in tracing any *progressive* variations to amphimixis. It could not, that is, evolve a bird or a mammal from a reptile. It is true that it may bring about new combinations of already existing characters. A cross between two varieties of sweet-pea may result in new kaleidoscopic shiftings of colour. A colt bred between a cart horse and an Arab would in some points favour its sire, in others its dam, in others might recall its grandsire. But no single point would be a novelty. Besides this, it is maintained that when reproduction takes place parthenogenetically (when there is a mother but no father), there is no less variability in the offspring than when there are two parents. In the aphides, or "green fly," on roses, parthenogenesis continues for a number of generations. But sexual generation recurs at intervals. In one species (the small crustacean *cypris reptans*) sexual reproduction has, according to Weismann, disappeared altogether. Of which, in spite of the evidence he adduces, we may have our doubts. For our present purpose the important question is, whether among "brethren" produced parthenogenetically (*e.g.* aphides) the range of variation is as great as among brethren whose origin is biparental. Professor Karl Pearson is satisfied that it is so. But the evidence is very slight. The organisms among which parthenogenesis occurs are extremely small, and our estimate of the range of variation depends on feats of very delicate measuring. We get much more dependable evidence from non-sexual reproduction in plants by means of buds, cuttings, tubers. Here, save in quite exceptional cases, we find that there is practically no variation. All the apple trees obtained by grafting from one original show no variation, nor do potatoes when propagated by tubers. It is true that we find often on one and the same tree, *e.g.* on the ash, great variation in the number of leaflets (I have found it range on one tree from

Parthenogenesis

17 to 8, on another from 11 to 3), but probably this hardly is more than a question of size. One leaf gets more sunlight than another, or being on a side branch is not so well supplied with nourishment. The weaker stems of the hop and the bramble often bear pairs of leaves that do not match, one being completely and the other incompletely lobed, and this defect of growth may well be due to want of sunlight.[1] Such differences are probably only a matter of growth due to inequality of nourishment. But we do, exceptionally, find a plant producing flowers or fruit of a markedly different type from what it has hitherto borne, and it is quite possible that these non-sexual variations are true mutations, as they have recently been called, the mutations which, there is much evidence to show, are the real species-builders. A peach tree that has never before deviated from correct and normal ways will take to producing nectarines. A chrysanthemum which had been raised from seed once gave rise, by bud variation, to six different varieties—they may have been worthy of the name of species. Five were distinguished by the colour of their flowers, one by its foliage.[2] I once found a primrose with fifteen petals, the other blossoms on the plant being normal. Later on I shall have occasion to speak of a remarkable case of bud-variation in the common Toadflax. On the whole, it looks as if the smaller and more fluctuating variations are traceable to amphimixis, whereas the larger architectonic changes arise non-sexually, through fission, as I have argued above. We do not often come across them. There is reason to believe that through long-continued selection in an environment that changes but little, species tend to acquire greater and greater fixity. In the early days of evolution such architectonic variations or mutations may have been of more frequent occurrence.

The *raison d'être* of amphimixis

Since, therefore, there is a good deal of evidence to show that amphimixis brings about only the smaller, more fluctuating vari-

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[1] See fig. 93, p. 234.

[2] I quote from Vernon's *Variation in Animals and Plants*, p. 186, an excellent review of the subject. Darwin's *Animals and Plants under Domestication* is a storehouse of information.

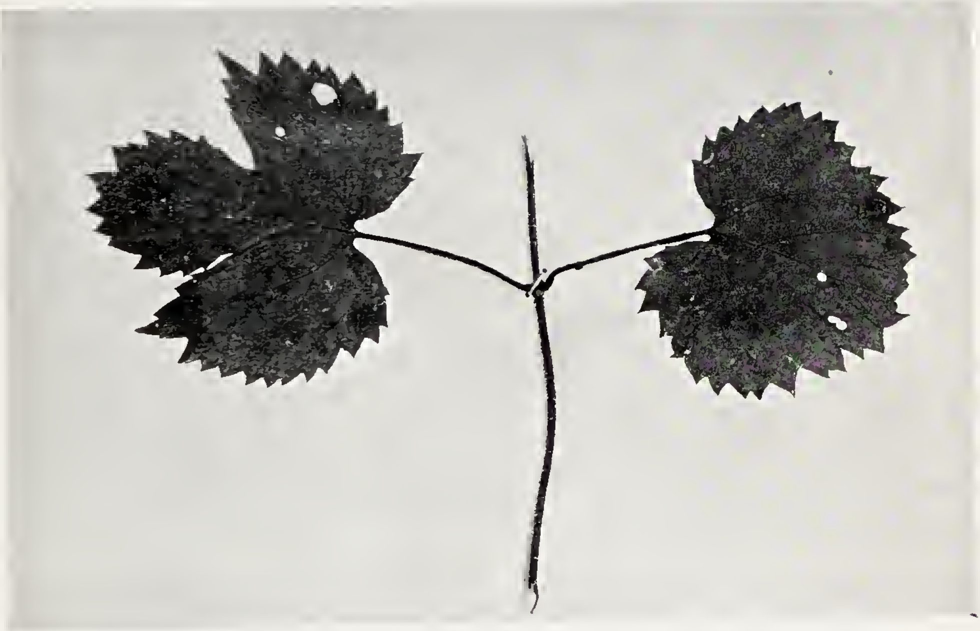

FIG. 93.—A pair of Hop-leaves.

Facing p. 234

ations, or such as represent only new combinations—a reshuffling of the cards—we must find for it some other *raison d'être.* It is universal, or almost so, in the organic world, and cannot be of secondary importance. There can hardly be a doubt that it is, what a thousand quack concoctions profess to be, a restorer of lost vitality, a means of rejuvenation to the senile organism, impoverished and reduced by long-continued fission. Maupas' wonderful experiments with infusorians proved this clearly to everyone except Weismann, who was already wedded to an untenable theory. When Maupas' infusorians pined and ceased to divide, conjugation with others of the species, but not derived from the same individual, put new life into them and set the process going again.[1] The variability that belongs, in greater or less degree, to every species of organism we must trace to a different source, viz. to fission.

Strength of heredity due to Natural Selection

But if fission—the method of reproduction that is universal in the organic world—is the main source of variability, how are we to account for the strength and constancy of heredity that is no less universal? How is it that some species of molluscs have continued for millions of years almost without perceptible variations? How is it that the Algerian blackbird maintains generation after generation its slight difference from the ordinary European form? The same puzzle arises with numbers of Algerian birds. They are so like ours, and yet not quite like. Small variations arise, and, if they are in no way injurious, heredity often maintains them, even though they are of no advantage. Here we have a thing very difficult to explain. But, whether we turn our attention to the apparently non-adaptive characters or to such as are obviously adjustments to the environment, in either case we find proof of the astonishing strength of heredity. How are we to account for this? When one-celled organisms first originated on the earth and multiplied by fission (to explain how this process began hardly comes within the scope of this book), the resultant halves must often have been so unequal, so unrepresentative of the parent organism, that they were unfitted to survive. Only those that bore a comparatively close resemblance to the mother cell would have a sufficiency of vital constituents. There would be continual weeding out of failures, so that fission would tend to become more and more equal, and the principle of heredity would be continually gaining in strength. Thus Natural Selection, by continually checking inequality of fission, has made heredity universally so strong that we have come to regard it as a primary fundamental fact that the offspring should closely resemble their parents. We look upon variability as the thing to be accounted for, whereas what we really have to explain is the faithfulness of heredity, not those occasional deviations from it which evolution turns to account for the development of new species.

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[1] See Maupas' two papers in the *Archives de Zoologie Experimentale et Générale*, 1888 and 1889.

Degeneration

To Natural Selection heredity owes its strength. As soon as Selection becomes less stringent, heredity tends to fail. There are many modern evolutionists who, without any thorough study of the subject, fashion airy theories as to civilised man and the lines along which he is to evolve, and one of the views that finds most favour with these philosophers is that Natural Selection has done its work, has made the human race what it is, and has bequeathed to it an irreducible fund of physical strength and vitality for socialists and humanitarians to play with. Even De Vries, the distinguished Dutch botanist, a man of very different stamp, has spoken of the human race as a fixed type (Dauertypus). Its fixity, as far as it exists, is due to the working of Natural Selection, not only in the past but in the present. It still eliminates nearly fifty per cent. of each generation, even in civilised England, for nearly fifty per cent. of our population die before the average age of marriage. There is good reason to believe that no species, not even the most conservative of conservative molluscs, could long maintain its type were there a total cessation of Natural Selection. Look where we will in the animal world, we find evidence of the shedding of organs that are no longer necessary, because unsuited to the

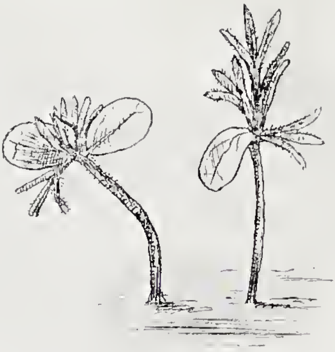

FIG. 94.—Young Gorse plants. They have one pair of trefoil leaves, the first after the seed-leaves.

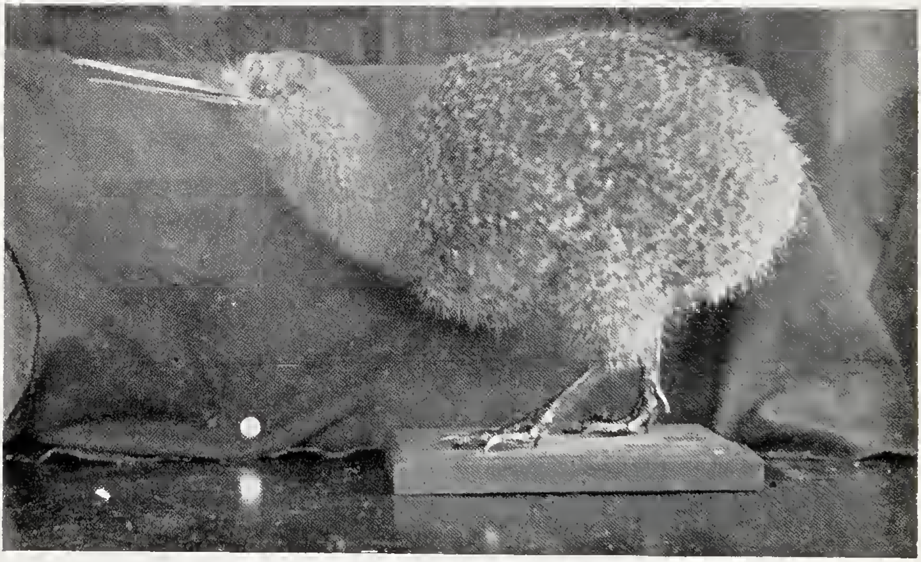

FIG. 95.—Apteryx (Kiwi). Real height rather over four times as great.

Facing p. 237

Shedding of useless organs

present environment. The young gorse plant, before it develops spines, bears one pair of trefoil leaves, the characteristic form in leguminous plants (fig. opposite). It drops the trefoil leaf because it now wants something different. Birds and mammals have in an early embryo stage what are demonstrably gill arches, though they never bear functional gills. The arches disappear, and, in the chick, vestiges of three of them survive in the lower jaw and the hyoid bone that supports the tongue. It is most important to hurry through these embryo stages, and, Natural Selection no longer defending them, the now useless structures do not remain long upon the stage of life. No doubt it would be better for the organism if they could be reduced and reduced till they were non-existent. Still an evolutionist has no right to complain that gill arches may be seen in the early days of the chick within the egg. Judging by its heart, the young bird is in one of its stages a reptile, a phase that closes with the fifth day of incubation. It just shows itself and passes away, after the manner of so much organic machinery that has done good work in its time and is now out of date. Structures that are not selected by the environment for survival fall into dilapidation, then vanish altogether, or leave only a vestige for men of science to note and ponder over.

Everywhere, whether in plants or animals, we find important organs discarded as soon as they become useless. The New Zealand Apteryx or Kiwi has lost its wings (fig. opposite). Minute remnants may be felt beneath the feathers. The dwarf barnacle, after its free-swimming larval life, fixes its head on a rock and loses its eyes and other important organs. In the caves of Carniola there is a blind amphibian, the Proteus. In the Mammoth Cave of Kentucky are blind fish. In the depths of ocean are numbers of blind fish and crustaceans. The common mole has eyes much reduced in size and almost buried in fur. Whales have lost their limbs altogether, and only a vestige of the pelvis is to be found. The Ornithorhyncus or Duck-billed Platypus has teeth in its early youth, but they soon disappear and give place to a horny bill. Cattle have no upper incisor teeth, have not even vestiges of them in their youth. The worker bees are females in which the sexual organs are not developed, though they occasionally lay eggs under the stimulus of a rich diet. The worker ants no less are females in whom all that pertains to sex is vestigial. Some slave-keeping ants have no longer the power of feeding themselves. Many of the beetles in Madeira have lost their wings. The Ephemeridæ[1] have lost their jaws. Their life is so short that it is not worth while eating.

In most of these cases the loss is traceable to the active working of Natural Selection. It is best for the chick that the gills of its embryo life should remain undeveloped and be short-lived. Fully developed they would be worse than useless within the egg. It is best for the proteus of Carniola and the fish of the Mammoth Cave of Kentucky to lose their eyes, since in the dark so delicate an organ as the eye is liable to accidents. To a mole good sight and a large eye would mean disease, suffering, and, before long, death. A whale with its method of swimming might find arms and legs an incumbrance. The wingless beetles of Madeira are saved by their winglessness from being carried out to sea by the wind. In many cases the lost organ, though it would not if present have impeded its owner or exposed it to danger, would yet have required for its production more vital energy than the organism could spare. Worker bees are stern specialists who shorten their lives by overwork for the good of the hive. They have no time or vitality to expend upon reproduction. Hence their sexlessness. It may be that long ago the power of flight, now lost, was a source of danger to the Kiwi. In any case the growth of wings and wing muscles and the annual production of strong flight feathers would have taxed its vital force. As it is, its strength has passed into its legs, which are uncommonly strong. It can run quickly and give a very vigorous scratch, whether in self-defence or to dig up the worms which form its chief diet. It is a night feeder, but, curiously, its eyes are very small, very unlike those of the owl. It seems to depend on touch, and perhaps more on scent (see p. 116). It has long bristles suggesting a cat's whiskers at the base of its beak, and the openings of its nostrils are at the further end, not close to the head as in other birds. The reduction in the size of its eyes illustrates our present subject. There is no need for the big eye of the typical night-feeding bird, for other senses have very largely taken the place of sight. And possibly if the Kiwi had the eye of an owl, there might be risk of injury as it wandered in the woods at night.

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[1] *E.g.* the Day-flies.

We have now reviewed many examples of loss, complete or almost complete, of organs that in various ways imperilled the safety of the organism or demanded an excessive expenditure of vital force.

Loss of organs that are useless though not injurious

Is there any evidence of similar loss or reduction when an organ is not injurious in either of these ways, but is left unprotected simply because it is useless; when the question of survival is unaffected, the full development of the organ or its dwindling to a vanishing remnant making no difference? When, with it or without it, the organism is equally well equipped for the battle of life, the character in question being either useless or a mere luxury? Among civilised men we undoubtedly find examples of such loss in plenty. Undoubtedly it is an advantage to have good sight instead of being dependent on spectacles. But from the point of view of evolution good sight has become a luxury. Survival does not depend upon it. Myopia, therefore, is on the increase. Good teeth are most desirable, but in these days of dentistry and elaborate cookery very inferior ones will do, whatever painful experiences they may occasionally bring. The prepeptonising of food threatens even to make the digestive apparatus, or part of it, a superfluity. In the United States such pains have been taken to educate deaf-mutes and enable them to earn a living that there is an increasing number of them. They intermarry and leave deaf-mute descendants. It is far better to be able to hear and speak, but education has made hearing and ordinary speech not absolutely necessary. The delicacy of many domesticated animals is very remarkable. We see it notably in highly bred horses and dogs and in some breeds of poultry. In some cases it may be partly due to in-breeding, but this occurs largely among some species of wild animals without bad results. Mainly the delicacy of domesticated stocks is due to the slackening of Natural Selection. In place of it there is artificial selection and the breeder selects for certain "points," and general vigour and stamina are a matter of secondary consideration. What we call strength of constitution tends to be lost, certainly not because it is injurious, but because survival does not depend upon it.

Loss of powers or organs often sudden and complete

The way in which the loss of unprotected organs often comes about is a thing to ponder over. We have a hornless breed of cattle. Sometimes not a trace of a horn remains, sometimes there is a vestige dangling. Breeders have, no doubt, selected hornless individuals and made a hornless breed. Still, it is probable that not much artificial selection was required, for losses such as these are often sudden and complete. The loss of wings in the Kiwi, of limbs in the whale, of the upper incisors in cattle, of sight in Proteus or in Kentucky fish—such losses may all have been (as in many cases congenital deafness is known to be) of sudden origin, complete when they first appeared. On the other hand, to build up an elaborate organ—limbs, ears, eyes—is a matter of many thousands of generations, even though, as I hope to show, the variations that have brought about evolution were rather larger than Darwin imagined. The onward steps are as nothing compared with the backward ones. Pulling down is always easier than building up. According to Buddhist doctrine, I believe, it is far easier by a random life to forfeit your humanity, sink when you are next reincarnated to a lower plane and become *e.g.* a monkey, than to accumulate merit and rise to a higher level of virtue and serenity.

A few more examples, since there are evolutionists who do not appreciate the difference in space between backward and forward evolution. A duck may be born—examples have occurred in domesticated breeds—without any webbing between its toes. The hens of some breeds of fowls have lost the habit of sitting. This defect may appear suddenly and completely in an individual, or you may have bad "sitters" who forsake their eggs after a few days of incubation. Here is the failure of an instinct which in wild nature is indispensable. In these days of incubators and "artificial mothers" it is unimportant, and, even before the days of incubators, the eggs of bad sitters could be transferred to good. Thus an instinct—even the deep-rooted maternal instinct—when Natural Selection ceases to brace it up, tends to disappear, and may disappear suddenly. Wild species, though as a rule they show more stability, are not exempt from such losses. The phenomenon of albinism sometimes appears without any warning in a wild stock. We see a white blackbird or pheasant (if pheasants can be called wild), or a cream-coloured mole. In these cases, probably, sexual selection sets matters right and no albino wild race is formed, but our white rats and mice show that very little encouragement is needed. Whales have lost their hair. It was useless, since they had blubber to keep them warm. It was probably harmless, to judge by the way the furred seals swim. Being useless, though harmless, it disappeared, and probably not by a gradual thinning but by a sudden denudation. In man the loss of a general coating of hair has not been so complete. But in his case too the explanation is probably the same. In hot climates it was a superfluity. It had no survival value and it went. We can hardly agree with Darwin that female taste tabooed it and so sexual selection exterminated it.

We see, then, that organs and instincts, when they become useless, drop away (though they may linger as mere vestiges or, *if insignificant*, may be protected by correlation with other characters that are useful, or by the conservatism of the organism), and that the backward steps compared with the forward ones are as a giant's strides to a dwarf's. But these backward steps do not occur when Natural Selection works freely. They occur in places where the strain of competition is relaxed, in quiet lotus-eating regions, in oceanic islands, or where ocean currents bring food, so that hunting is unnecessary. They occur among parasites, or among domesticated animals, or among civilised men for whom science and philanthropy soften the environment. In such cases we speak of loss as degeneration. But it must not be forgotten that there is also loss which is not degeneration. It often happens that the advance to a higher and more complex state is necessarily accompanied by loss, by the shedding of what has become useless. The acquisition of lungs involved the dropping of gills.

The Steps by which Evolution advances

We must now return to the starting-point of our investigations, to the one-celled organism. In this lie wonderful potentialities, and the development of these has gone on till we have as the greatest triumphs of evolution the birds and the mammals, among the latter man, their crowning glory. The environment has ever been favouring some variations and discouraging others, discouraging them to the extent of prohibiting them altogether. And this work of the environment, selecting some for survival while condemning others, is called Natural Selection. We have here evidently not a force, but merely a regulating principle. The only force is the wonderful vitality of protoplasm, the substance of which all living organisms are built up. The smallest micro-organism, in its one cell, contains in a rudimentary form all the wonderful powers that we find in the highest forms of life. So that the theory of evolution has not robbed the world of its wonders. Rather it has made it still more wonderful. We have still the human brain to marvel at, the human brain with its wonderful power of scanning the universe, of studying both itself and the world of phenomena around it. But evolution has brought to our notice something no less wonderful, the single cell of protoplasm, from which in the course of millions of years has been developed the human brain, the paragon of all the things the world has to show.

We have discussed the cause and the tendency of variations. It is now time to investigate their character further. *Natura non facit saltum* is an ancient aphorism and, unlike most of such naïve assertions of what ought to be and is, it has found favour with men of science in modern times. Geologists and botanists have maintained its truth. Darwin investigated and discussed the comparative importance of large and small variations, and decided that the smaller greatly outweighed the larger in

Darwin's view

importance. He held that evolution had proceeded, not by leaps and bounds, but by minute steps, and that Natural Selection pronounced its verdict, favourable or condemnatory, on each small change. The occasional sports which appear, he thought, would rarely leave any traces, owing to the swamping effects of intercrossing. He was quite aware that Japanned peacocks, with their very special colouring, sometimes appear as a sudden sport, and that in two cases, at least, they have multiplied and extinguished the common breed, so prepotent were the Japanned birds. He considered carefully the case of the historic Ancon sheep, short in the leg and valued highly because it was bad at getting over fences. This Ancon sheep transmitted its short-leggedness. It was so prepotent that its offspring were true Ancons, and in their turn produced true Ancons, though mated with sheep that had the ordinary length of leg. Here was a clue to much that was difficult in evolution, but the case was looked upon as far from typical. Other examples of sports were quoted which had not perpetuated themselves: there was no prepotency or not the required degree of prepotency. But more evidence has now come to light. A distinguished Dutch botanist, De Vries, has undertaken to show that it is only mutations (changes in most cases large, and which, large or small, are transmitted to after generations) that count for anything at all, and that ordinary variations are nothing but fluctuations that have nothing to do with evolution. In support of this view he has given a good deal of evidence. Most of our garden fruits and vegetables are, according to him (and he speaks with authority), not the products of a long course of selection but, sudden sports improved slightly by the selection of the best of the fluctuating variations, perhaps by the accumulation of small mutations subsequent to the original one, but not to any very great extent altered. To make clear what is his conception of a variation he quotes with high approval Mr Francis Galton's simile. A species behaves like a polyhedron which rolls and rocks but always comes to rest on one of its existing faces. (An illustrative polyhedron can be made by taking a cube of wood, a child's "brick" for instance, and

Mutation

sloping off its corners.) So a species oscillates from one position of organic stability to another. A mutation, on the other hand, brings about something new. The species comes to rest on a new position of organic stability. A move onward is made, and as a rule there is no return: a mutation, as a rule, is transmitted to subsequent generations. But though there is stability, there may be great variability, only the mutation causes the species to oscillate round a new point. Variations, on the contrary, do not breed true. They are mere fluctuations, and the species "gets no for'arder." Mutations De Vries distinguishes also from monstrosities. The latter affect some part only; mutations, the whole organism. The mutation theory originated with the study of Oenothera Lamarckiana, a species or variety of Evening Primrose. It is thought to have been imported from America, but it is now naturalised in Holland. De Vries found it growing in abundance near Amsterdam. Not only was it variable, but he soon discovered that it was in a state of mutation. He experimented for seven years on this Evening Primrose, and grew and had under observation in all fifty thousand plants of it. He obtained by sudden mutation twelve new types, of which nine were constant and three fickle and inconstant. Other new forms there were, but they were too weakly to survive. They differed as to size, as to thickness of stem, as to breadth of leaves, as to size of flowers, smoothness of leaves, and many other points.

Evening primrose

Toad-flax

He has also experimented on many other flowers, and with marked success on Toad-flax (*Linaria vulgaris*). On a plant of this he noticed one or two flowers that were regular, round, that is, with all the petals approximately of the same make! There were five not quite equal spurs instead of the usual *one*. These regular flowers were sometimes barren. When he could get no seed from them, he got it from the ordinary one-spurred flowers on the same plant, and after eight years' breeding and selection he obtained a race of regular-flowered toad-flax which seldom failed to breed true from seed. Mutation first showed itself suddenly in particular blossoms, then in all the flowers of two individual plants, and now the race is constant or nearly so.

De Vriesism (to coin a word) seems like a bomb flung at orthodox Darwinism. It is true, as De Vries says, that variations do appear to be mere oscillations, and that they do not, apparently, lead to progressive evolution. In spite of the most careful selection there is no improvement now in the breed of horses, and, I believe, the same may be said of cattle and sheep. Still, when we apply the mutation theory to animals, there is or may be a difficulty. The species of plants that arise by a sudden mutation generally breed true *when there is no intercrossing*. Artificial selection, as De Vries says, weeds out the forms that are "corrupted by crossing," the work of insects. When a sport arises in a species of animals, it must inevitably run the risk of such corruption. It may be defended by prepotence, whether due to inbreeding, as it often is, or arising independently. We hear little now of the necessity of isolation for the formation of new species. Professor Cossar Ewart, who has unrivalled experience in the breeding of animals, holds that prepotence does away with the necessity that a variation should appear simultaneously in several individuals, and that they should be isolated from others of the normal build. Still prepotence sometimes fails. Intercrossing sometimes plays havoc with a sport or mutation, and even wild species are in many cases interfertile, *e.g.* different species of cattle, deer, and ducks. The mutation theory originated, not unnaturally, with a botanist. Its application to the evolution of animals is not free from difficulty.

Mendelism

But we can find support for De Vries' theory in Mendelism. Mendel was an Austrian monk whose experiments, neglected during his lifetime, are now modifying men's views on evolution. He published an account of his experiments only five years after the publication of Darwin's *Origin of Species*. But till a few years back they remained unnoticed and unknown. Mendel experimented on plants, and notably on the Eating Pea (*Pisum satisum*), a plant admirably chosen, for it is rarely if ever fertilised by insects. He crossed different varieties, *e.g.* the tall and the dwarf, those with yellow, those with green seeds, and so forth, studying in each case a particular unit character. In the first generation produced by the cross of tall and dwarf, all were without exception tall. But in many of these dwarfness was latent. For in the next generation, each flower being self-fertilised, only 75 per cent. were tall and the remaining 25 per cent. of the dwarf form. The generation after this brought further wonders to light. The 25 per cent., the dwarf plants, all bred true. Of the other 75 per cent., only $\frac{1}{3}$ bred true; the remaining $\frac{2}{3}$ produced 75 per cent. tall, and 25 per cent. dwarf plants. After the original cross, the flowers were always allowed to fertilise themselves.

I must now give up narrative and trust to a table (fig. 96, p. 246). But I must point out two things, and those the most important, that had become clear: (1) the characters did not blend, the offspring were definitely tall or dwarf, not half and half; (2) the tall form was dominant (Mendel's word for prepotent), and the dwarf was recessive. Other terms are explained at the foot of the table.

When other characters were experimented on, the results were the same, so that the table may be made general by substituting dominant for tall, and recessive for dwarf. What strikes us most on first thoughts is the numerical symmetry and the astonishing way in which it is maintained. The impure tall always give pure tall, impure tall and dwarfs in the proportions 1 : 2 : 1. There is no impure recessive. In the impure tall the recessive character is latent, ready to appear in the proper percentage in the next generation. All this is not so hard to explain as it looks. In the first generation after the cross we may consider the tall and the dwarf to be equally represented, though the dominant character alone appears. When the ovules are fertilised by pollen from the same parent plant there will be equal numbers of tall pea and dwarf pea ovules, and unlimited pollen grains in which the tall and dwarf are equally represented. Let us imagine 400 ovules, of which 200 represent the tall form, 200 the dwarf. Then come in the pollen grains, half of them tall form, half of them dwarf, and we get, according to the laws of chance, as the result of fertilisation:—

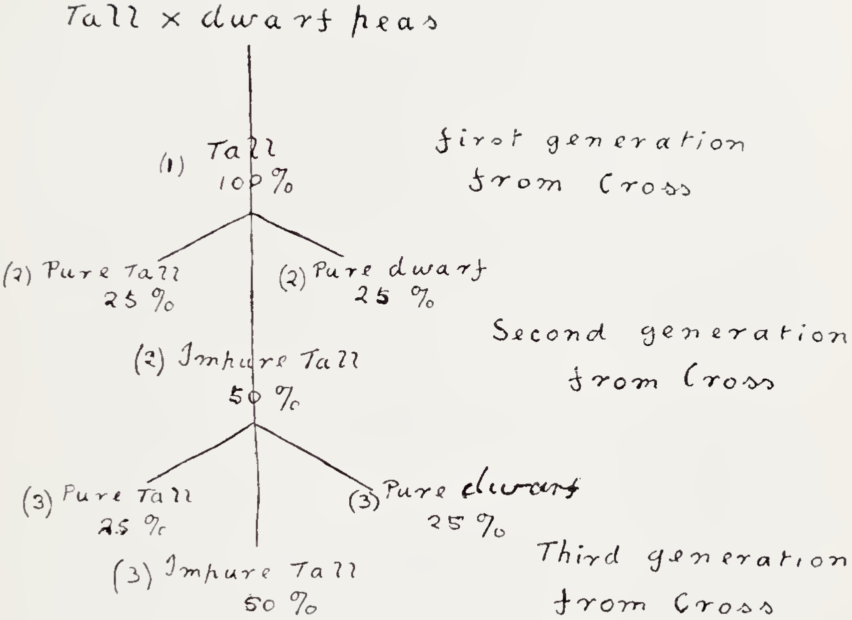

FIG. 96.—Diagram illustrating Mendelism. Pure means breeding true; impure, having mixed offspring, some tall, some dwarf.

dominant over the "single" serrated combs of Leghorns and Andalusians. In all the cases mentioned the two alternatives or allelomorphs refuse to blend. There is in the offspring of the crossed mice either a white coat or a brown coat, not a light brown one. The round peas and the wrinkled have given rise to much fighting. It was maintained that there were dubious specimens qualified to figure in either category. Not a few were photographed, and the camera, of course, cannot take sides. Some of the round and smooth did look, it must be owned, very wrinkly when thrown on the screen by the magic lantern. But as one party had called in the camera, the other called in the microscope, and, when the starch grains of the two kinds of pea were examined by its help, it was found that they were of quite different shape. Here was a triumph for the Mendelian.

But we cannot expect that the triumph should always be absolute and complete. We do sometimes find cases of blending. Galton found this with human stature. A negro blend shows itself in what we call "a dash of the tar-brush." The tendency shows itself, though but slightly, when a white Leghorn fowl is crossed with a brown Leghorn. All the offspring are white, but "ticks" of brown almost always appear to prevent Mendelism being too theoretically exact. Still the general principle remains true. When varieties are crossed, the characters remain pure, unblended, and, of two alternatives, one is dominant, the other recessive. For a further account of Mendelism, I recommend my readers to Mr Punnett's excellent little book.[1]

De Vriesism and Mendelism

We can now return to De Vries and his theory. It is at once apparent that Mendelian dominance and non-blending strongly support it. When a mutation appears in a plant, it can without difficulty maintain itself. Even in an animal, dominance or prepotence may save it, and by the help of inbreeding, a thing very common in some wild species, pure dominants may arise.

Natural Selection and mutations

And how does Natural Selection fare at the hands of these upstarts, Mendelism and De Vriesism? To those who have always taken a right view of Natural Selection it remains with its importance not very much reduced. It never was anything but a regulative principle. Variations arose, Darwin held, and some were selected by the environment for survival and others were eliminated. The same thing goes on, according to De Vries' theory, but there is this difference, that when a mutation arises it is, he believes, from the outset stable, so that Natural Selection does not have to produce stability, but only to select what is already stable for destruction or survival. In most cases, too, according to De Vries, the onward steps are longer than was formerly imagined. No doubt Darwinism does not remain unscathed; but it is still on its legs, and will remain so, even if the new theory has not to be qualified. Mutationists admit that no type of plant or animal survives if Natural Selection withholds its imprimatur. Nay, the very fact (let us grant it to be a fact) that evolution proceeds by mutations, that there does exist the tendency to produce them occasionally as a means of adaptation to environment, must be due to Natural Selection. Again, if Natural Selection becomes less stringent, regression and loss set in, and the species in question falls into dilapidation. The strength of heredity is still maintained by the working of the same principle to which it owes its origin. It is most important that we should not fall victims to Darwin worship and belittle the work of Mendel, Mr Bateson, and De Vries. Nevertheless, Natural Selection still remains the great regulator of organic life.

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[1] *Mendelism.*

Random character of variations

Let us now study further the nature of the variations that have formed the raw material with which evolution has had to work. I think that there is no doubt that they were, when evolution began, purely random deviations. They did not, so to speak, aim at and try to adjust themselves to any characteristic of the environment. And certainly the environment did not influence the organisms, vegetable or animal, and cause them to vary in accordance with its peculiarities. There is no evidence that any such influence is ever exerted by external conditions. The wind cannot cause the thistle to produce the thistle-down for it to waft over the fields. The bee cannot cause a plant to produce a bright flower to show to it and its associates where honey is to be got. Even exercise can do little. An elephant cannot by any imaginable form of exercise have caused his snout to grow into a long trunk. A man can only in a sense make his arm strong by use. He can only, that is, develop the strength that is there potentially already. If this is not clear, take the case of a bird's feather. A bird's feather is a thing with no life in it after it has once grown. It cannot have been exercise, then, which caused the wonderful wing and tail feathers of birds to become so perfect in every detail. And do not the wings of moths develop without any exercise during the chrysalis life of the insect? Neither the environment, then, nor exercise can account for variations or for the adaptation of organisms to their surroundings. As I have said above: We have to look to fission, to the division of the cell, for the primary cause of variability, and that being so, the variations must be random things, not aiming at the peculiarities of the environment; not, therefore, of necessity adaptations. Nevertheless, variations have not been throughout evolution *absolutely* random shots. Take a point somewhere in the course of evolution from which various new lines diverge, and this will become clear. Among existing reptiles we have as the three most conspicuously defined types the Lizard, the Chelonian (tortoise or turtle), and the Snake. The Hatteria and the Crocodile are really very different from Lizards, but I am disregarding all divergences except the very widest. Then there are the extinct Plesiosaurs, Ichthyosaurs, Dinosaurs, Pterodactyles.[1] Now, when reptiles first developed with their three-chambered reptilian heart and their characteristic brain, it was possible for them, so to speak, to choose various lines for further evolution. They might become tortoises, slow of movement, roofed with a bony casing that deprived their backbones of all free play. Or they might evolve as lizards, moving by short quick spurts, and with supple backbones, with ball and socket joints between the vertebræ. Or they might lose their limbs altogether, and move by means of the lithe windings of backbones still more supple than the lizard's. And there were also as possibilities for them the various forms now extinct. But when once a reptile had definitely adopted one line or another, had become a sort of

A limit to the range of variation

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[1] And the Theromorpha.

tortoise for instance, he could not then try one of the other lines of development and become, *e.g.*, a snake. Birds, again, are reptiles of a nobler form. When once a reptile had attained to the dignity of a bird there was no going back. The onward movement from reptile to bird was a possibility. The journey back, from bird to reptile, is out of the question. It is true that we find many instances of reversion, as they are called. But an animal never completely reverts to what it was at an earlier stage of development. It may lose some of its characters, but it still belongs, however degraded by the shedding of them, to the highest class to which it had lifted itself. A barnacle is still a crustacean, and a near relative of the crab and the lobster, though it has lost its eyes and its power of swimming. The apteryx is still a bird though its wings are almost gone. So that, when in evolution a plant or animal has advanced to a certain stage, it can vary only within comparatively narrow limits: a tortoise can only evolve some variety of tortoise, a horse some variety of horse. In order to take a widely different line it would be necessary to descend again to a point much lower down on the genealogical tree, and no such descent, as I have shown, does, as a fact, take place. Variations, therefore, lose a great deal of their random character as evolution proceeds. They are chance things still in the sense that the hits made, the adaptations effected, are coincidences, but the range of possibilities is always being reduced as the characters that mark the forms of life become more and more definite.[1] The primitive reptile contained in it wide potentialities—the tortoise, the lizard, the snake, the crocodile, the Pterodactyl, the Dinosaur, the Theromorph, and other fossil forms, the bird, too, and even the mammal. A bird has no such wide range of potentialities in it. If it goes on to further evolution, it will refine and still further specialise its avian characters. It will develop in fact as a bird. Even its variations are subject to heredity. They must harmonise with the general character of the type just as much as the features which are absolutely normal.

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[1] Compare a safety range. Each successive barrier between marksman and target narrows the amount of deviation possible. The bullet may pass the last and yet miss; it cannot go far wide.

Adaptations

Now a further question obtrudes itself. If the range of variations is thus limited, how can adaptations be effected?

When we think of the perfection to which adaptation is in some cases carried, it is on first thoughts very difficult to imagine the process by which it has been brought about. There is the Kallima butterfly, celebrated for its perfect imitation of a dead leaf with a touch of mould on it. There is the woodpecker, with its wonderful tongue, armed with backward-pointing bristles, and with its special arrangements for protruding this very long tongue, the whole making up a marvellous piece of machinery for extracting insects from under the bark of trees or from decayed wood. His feet too, and his tail feathers, are specially adapted for climbing (fig. 97, p. 254). There is the chamæleon with his, perhaps, equally wonderful tongue, which he keeps rolled up (the only way of packing its monstrous length in his mouth), and which he shoots out like a flash of lightning. There is the almost perfect mimicry of one butterfly by another, the mimicry of the poisonous or nauseous by the non-poisonous or palatable. There is the hollow in the back of the infant cuckoo, specially adapted for shovelling out eggs or foster-brothers from the nest. All these things are wonderful adaptations. But let us think how the first rough adaptation probably arose, instead of contemplating the finished masterpiece. Probably at the outset mere coincidence accounted for a good deal. A few examples will make this clear. A butterfly may trust for its safety to strength of flight, or its nauseous taste, or its protective coloration. Mere coincidence, due to a random variation, may in the first instance have made the progenitors of the Kallima butterflies rather like dead leaves. Thus they would come to trust to protective coloration. Those that were strongest in this, the established policy of the species, would survive. The comparative failures would be snapped up by birds or other enemies. Thus mere coincidence may account for the first rough resemblance. Many generations of selection may bring it to perfection.

Plants have wonderful adaptations, though they are hardly equal to those we find in the animal world. Flowers have most remarkable contrivances for shaking their pollen on to the heads of welcome visitors, such as bees, and long thin tubes to prevent the unwelcome, such as ants, from getting out their honey. The long tube is a first-rate adaptation to the long proboscis of the bee. Some flowers, most of the orchids, for example, are incapable of self-fertilisation. The pressure of the bee's head is wanted to bring the pollen masses from their little pouches. They, the pollen masses, are provided with wonderful cement, so that they adhere too tightly for any shaking or any wind to dislodge them from the head of the bee. Here, again, is a perfect adaptation, or a near approach to it. But let us once more consider the first beginning, and not the *chef d'œuvre* that we now see. At the outset a plant, in order to obtain cross-fertilisation, can choose, so to speak, between two methods. It can produce pollen in plenty, and trust to the wind to carry it, or it can make provision for attracting insects by its bright colours or its scent, and so get them to carry the pollen. Supposing it adopts the latter course, various alternatives present themselves. It may trust to colour alone to attract, and waste no vitality on fragrance, or it may trust to fragrance alone, as the lime tree does. It can choose any colour or colours to be found in the spectrum. It can choose any shape of corolla. But when once it has chosen its method of adaptation, decided on its line of policy (I am obliged to speak of it as making a choice, which of course it does not), it is then bound to proceed along that line. The lime tree is bound to go on improving its fragrance; it cannot, like a politician, perform a complete *volteface*, abjure scent, and go in for colour. The pine tree cannot throw over the wind and appeal to insects to carry its pollen. Once a particular line of adaptation has been adopted, the plant or the animal must continue along that line. But at the outset the environment allows the utmost freedom. The only thing that is insisted on is efficiency. Each primitive organism is allowed a free hand, it may clutch at any means of safety. But when once it has entered on a particular path there must be no looking back. Think of the way the desert plants protect themselves. Many are armed with thorns, and the thorns are of various origin. Some are branches, some hardened cells, some hardened leaves. Some desert plants are poisonous, some are nauseous, if not actually poisonous. Some are tough as string, and wiry in addition. The colocynth trusts to its nauseous flavour and poisonous properties. It has pretty green leaves, rather like those of the common briony—it belongs to the same family. Its fruit is a small, round gourd loaded with pips. When there is a great hurricane blowing, this small gourd goes bowling over the plain, and so the colocynth makes settlements in new territories. The camel, who can stomach most things, fights shy of the colocynth. He prefers thorns or wire-like grass. The thorny leguminous plant shown in the illustration (fig. opposite) he will single out as especially appetising. It has very minute green leaves in the axils of the spines, and to get at these he crunches up the plant, spines and all. Altogether desert plants form a very unappetising assemblage. Each has brought its own peculiar kind of nauseousness to perfection. As camels, gazelles, donkeys, goats have gone on improving their powers of coping with a nauseous diet, the desert plants have tried to keep pace with them. It is a drawn battle between the plants on the one side and the animals on the other. Each plant has its own excellence, its own peculiar method of adaptation to its environment. To explain such first-rate adaptations, we must imagine mere coincidence producing something passable at the outset, an attempt at thorns or wiriness, at an unpalatable flavour, or at poison. Then selection works on through many generations, till at last a masterpiece is achieved.

Advance of species *pari passu*

It is much easier to understand adaptation if we bear in mind that mutually hostile species have advanced *pari passu*, the predatory sort keeping pace with those that stand on their defence. When butterflies first began to trust to protective coloration, the eyes of their persecutors were less perfect. As the butterflies have improved their apparatus and methods, so the birds have improved theirs. As the desert plants have grown more tough, more thorny, more nauseous, the moufflon, the gazelles, the donkeys, and the camels have improved in point of teeth and general capacity for dealing with such food. As the deer and

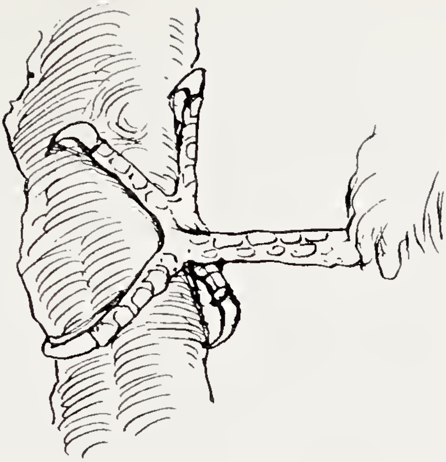

FIG. 97.—Woodpecker's foot.

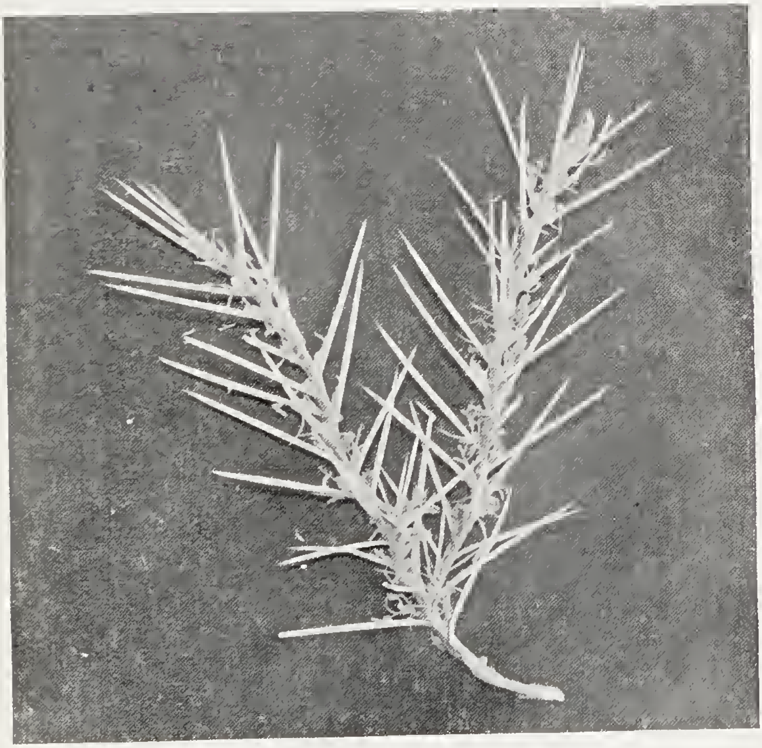

FIG. 98 (rather less than half real size).—A leguminous plant from the north of the Sahara. Considered good eating by camels.

Facing p. 254

the antelopes have gained in speed of foot, the carnivora that prey upon them have levelled up. As the birds that are hunted have improved in quickness and methods of concealment, the birds of prey have grown stronger on the wing, quicker of eye, and more deadly in their swoop. It is impossible to understand evolution unless we think of the environment as constantly making greater and greater demands, perpetually insisting on more perfect methods of adaptation. Clearly the physical environment, cold and heat, rain, snow, and drought could not supply an ever-increasing pressure of this kind. It can be found only in the living environment. Each species has been perpetually spurred on by those with which it came in contact. The advance must have been gradual, the species keeping pace with one another. Had it not been so, had some species altogether outpaced its rivals, some big premature carnivora, as active and fierce as the tiger, might have played havoc among the unwieldy reptiles of the Secondary period.

Waste

Nature is very wasteful and yet very economical. There is thrift even in her extravagance. For though the waste seems endless, yet everything that has proved a failure is used again for fresh experiments. It resembles, in fact, the Chinese circular system of agriculture. Horse chestnuts are produced by the million on the chance that there may be an opening somewhere for a tree or two. Very possibly all the outlay goes for nothing, but the chestnuts manure the ground and help towards the growing of a new crop that may have better luck.

Among the lower animals the system of reproduction involves far more waste than among the higher. Buckland estimated that the roe of a large female codfish contained seven million eggs.[1] Let us imagine that all these eggs fared well and grew into fish as large as the parent cod. Then supposing the sexes to be equally divided, the females would produce in one year 24,500,000,000,000 or twenty-four and a half million million eggs, "a thing imagination boggles at." But under ordinary circumstances there is no increase in the cod population. The portentous birth-rate is balanced by the portentous death-rate, due largely to the fact that the mother takes no care of her young. The egg, it is true, contains just a little food to tide the embryo over the first few days of life, but no attempt is made to drive off the predatory creatures with which the sea swarms. Compare with this wonderful extravagance the system we find in vogue amongst birds and mammals. Even the rabbit, proverbial for its rapid multiplication, produces only from fifteen to twenty-four young in the year, a great drop from the seven million of the cod.

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[1] See the *Royal Natural History* where Buckland is quoted.

Parental care

But neither birds nor mammals leave their young uncared for. In the bird's egg a great deal of nourishment is stored. The actual embryo may be seen as a small round disc on one side of the yolk. The egg consists almost entirely of nutriment for the young bird. Moreover, the parent birds (or, at least, the mother) do their utmost to protect the eggs, build a nest for them, and fight to protect them. Even those that are ordinarily quite timid develop wonderful courage in the defence of their eggs and young.

Among mammals there is a still better system. The young rabbit is not born till development has proceeded a long way, and, till birth, it derives nourishment from the body of its mother in the form of blood that has been already oxidised, so that breathing is as yet unnecessary. After birth it is suckled till it is fitted for such food as grass. All these wonderful developments and adaptations were necessary if the plan of trusting to mere numbers was to be abandoned and a more economical system was to take its place. We can contrast with the random casualness of the cod-fish the wren building an admirable nest, carefully concealed, devoting all her energies to the feeding of her young, aided by her mate, and, if need be, fighting in their defence.

Plants, as we might expect, are much more wasteful than the higher animals. No tending of their young is possible. But something they do. They develop contrivances for scattering their seeds to a distance so that they may not all fall close to the parent plant and be starved or stifled for want of light and room. And the seed itself is mainly a store of nourishment, enabling the young plant to get a good start in life.

Influence of the Individual on the Course of Evolution

But the tending of the young by the parents has led to other results besides economy. It will be remembered that I tried to show that no powers that were acquired during life can be transmitted to the next generation, and further, no powers can be in a true sense acquired. What we gain by practice and exercise is the development of powers that already exist. Though this is, I believe, true beyond all doubt, yet parents, by caring for their young, do indirectly influence the course of evolution.

It is the environment which selects for survival or dooms to death. If, then, the parents choose the environment in which their young shall grow up, they decide on what qualities survival shall depend, and so on what lines evolution shall proceed. The duck takes her ducklings to the water. They must swim and forage in the water or else come off but poorly. If the feet of some individual duck are not webbed—an abnormality that occasionally appears—he will not be so expert a swimmer as his fellows, and be in more danger, perhaps, of being snapped up by a pike. He is not at home, in fact, in the environment which his mother chooses for him. If not thus schooled and directed he might have tried a life on dry land. The young woodpecker is taken to decaying trees and sees his parents extracting grubs from under the bark. His means of livelihood is chosen for him. He must be good in that particular line or he will perish. He may have all manner of other strong points but they are likely to count for nothing, because his parents expect him to live as a woodpecker, and he probably has not originality enough to strike out a line for himself. He may invent such things as better ways of extracting insects, a better way of clinging to an upright tree trunk. Such things come within the permissible range of variation. He may even take to finding worms and such things in the ground, for this is not too wide a departure. But the life of a water bird, the habits of a duck or a flamingo—such things are out of the question for a young woodpecker. Hence under parental guidance evolution will tend to follow a particular course. For a time a species that has adopted a particular way of life may have difficulty in maintaining itself because the special adaptations required do not arise. The woodpeckers may not have the woodpecker tongue in perfection, the strong tail feathers, the zygodactyle foot, the remarkably strong beak. Still, through practice from their early youth onwards they will become fairly efficient at their work. Those that are moderately well endowed will survive, their moderate endowments, with the help of practice, coming up to the survival standard. At length further favourable variations will come, in tongue, feet, tail feathers, and beak, these being a woodpecker's "points." With these improvements the species will be able to meet a crisis, such as a dearth of insects, which might have annihilated it to the very last woodpecker, had it come before the improvement arose. In the case we have been imagining the variations have followed the needs of the species. It wanted improvements in its special adaptations and the improvements arose. This makes it appear as if exercise were the cause of the variations, the theory of the French naturalist, Lamarck, which dies so hard. But it is a question whether a bird's beak can be exercised in the true sense any more than we can exercise our hair. Nor has anyone ever succeeded in showing how a quality acquired by any part of the body can be transmitted to the reproductive cells. But it has now been made clear that, by adopting a particular habit of life and by developing particular powers and faculties by exercise, individuals are able to make shift, so that the species somehow rubs along till further variations arise, tending to perfect it on its own line of evolution. And then it looks as if it were advancing by means of Lamarckian methods, as if each improvement due to practice and exercise were handed down to the next generation.

The rudiments of parental instinct

It is interesting to trace the stages by which the system of parental care and guidance has grown. Among most of the invertebrates it has not come into being. But among some insects, notably among bees, we find it highly developed. The larvæ have their nurses and are carefully tended, and the workers toil during the whole of their short lives for the benefit of the hive. Turning to the vertebrates we find most fish doing nothing for their young. Like a boy who is turned adrift by his father with a sovereign in his pocket, each is supplied with a small store of nourishment in the egg and then left to himself. What more he requires he must get by his own wits and energy. Thus a cod or a herring does no more for her young than a plant does for hers—for his? for its? it is hard to know which to say. Take a Broad Bean, pin it onto a cork and float it in water. It will germinate, grow into a flourishing plant, will blossom and perhaps even ripen seed before at length it withers and dies. The seed is a large store of nourishment supplied to the young plantlet by the parent plant. In fact the young bean gets a much better start in life than the young cod or herring. But to return to fish. Some species, instead of laying eggs, are viviparous; they bring forth their young alive. Among these are some of the sharks and rays. Certain sting-rays are not only viviparous, but nourish their young before birth with a secretion analogous to milk.[1] In another fish, one of the Ophidiidæ, there are apparently a number of barren eggs which afford nourishment to the embryos that emerge from the fertile ones, just as young ostriches are said to be nourished partly on the eggs that the hen birds drop casually about, wide of the nest. The male stickleback, as everyone knows, makes a nest and defends it against all comers, among them his own wives, who are eager to eat the eggs they have laid. Proceeding to a class a little higher than fish, we find some development of parental instinct among Batrachians. A Brazilian frog, *Dendrobates braccatus*, carries its tadpoles on her back, carries them to where there is water for the young things. The Midwife Toad (found in Spain, France, Switzerland, Thuringia) is celebrated. The eggs are large, with much food yolk, so that the young reach an advanced stage—their gills being fully developed—before they hatch out. And it is the male who takes charge of the eggs. On Faroe Island, as I have already recounted, Mr Guppy found a number of round transparent eggs, not quite as big as marbles. Each of them contained a young frog about four inches long, with long hind-legs, short fore-legs, and no tail. The absence of tail showed that the tadpole stage was a thing of the past—it had been got over within the egg. On the breaking of the eggs the young frogs took a marvellous "leap into existence."[1] Some reptiles tend their eggs, or their young, or both. A python that incubated at the Zoo has become famous, not so much because of the motherly spirit she showed, as because of her remarkable temperature. I have told the history of this before. The clinical thermometer put between her folds pronounced on one occasion that it was 16.7 degrees above that of the surrounding air. If after six weeks of incubation the eggs were addled, it was not because the mother python was deficient in animal heat. We have nothing among British reptiles to match this python parent. *Lacerta vivipara* leaves her young to their fate though they are born alive, hatched out before birth, or, else, break the egg directly after it is laid. Crocodiles are animals of a rather higher order. The female lays several dozen eggs in the sand, sometimes making an elaborate nest for them. She watches over them, and when her offspring hatch out she takes care of and fights for them. Unprotected they would fall an easy prey to storks, fish, and other crocodiles. I find no evidence of parental affection among tortoises or turtles.[2] Dr Alcock describes young turtles just hatching out and looking like beetles.[3] By instinct they at once made for the sea, and often as he turned them and started them in other directions, they faced round and headed for the water. This perfection of instinct seems to show that their mothers do nothing for them. Whenever there is any education by the parents, instinct is weakened.

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[1] See Dr A. Alcock's excellent book, *A Naturalist in Indian Seas*, p. 70.

Above the reptiles we come to birds and mammals that devote themselves to the care of their young, feeding them, fighting for them, educating them, and deciding their environment. But when they are out of the nursery, the young bird and the young mammal are thrown upon the world and left to fight their own battles. It is, of course, in the human race that the family system is seen at its highest and noblest. There is no need to dilate upon so familiar a topic, but I recommend everyone to read Robert Browning's *Ivan Ivanovitch.* Ivan would never have gone unpunished for what he did, had not the idea of parental responsibility absolutely taken possession of the human conscience.

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[1] See Dr Gadow's *Amphibians and Reptiles*, p. 260.

[2] *Ibid.*, p. 447.

[3] *A Naturalist in Indian Seas*, p. 85.

Parental care and the struggle for existence

But we have to return to the question: How is evolution affected by parental care of the young? Obviously life is made easy for them. Yet, except among civilised men, the struggle for existence remains as intense as ever. Probably it becomes more intense. High feeding and something of education bring out whatever good stuff the young have in them. Then they advance into the arena, fight their fight, and win or lose. Thus there is much more real selection according to merit, and much less indiscriminate elimination. But a point on which I wish to lay stress is this, that the parents, by choosing the environment in which their offspring shall live, decide to some extent the line on which the species shall evolve. Though Lamarck's theory of the inheritance of acquired characteristics has turned out to be untrue, yet each generation can to some extent influence the future of the race. The human race, as science advances, has more and more power over its own future. It is difficult to feel sure that the use made of this growing power will be a wise one.

Gregarious species

As yet I have been speaking only of the family. We have now to consider, in the case of gregarious species, larger groups, flocks, herds, associations of all kinds. Take a herd of cattle first. The young bull will learn from his contemporaries in the herd to butt and fight. Among the rising generation will be many masterful dispositions, many hard heads, and he will have to give and take hard knocks or efface himself. A young curlew will pick up a great deal of knowledge from his elders, such things as whether all men are to be dreaded or only those who carry guns. A young rook will learn from experienced members of the rookery the difference between a harmless heron and a dangerous peregrine. The tradition of the species represented by the particular flock to which they belong will lead young birds to adopt a particular mode of life. In proportion to their efficiency in the particular arts required will be their chances of survival. And as in the case of the family, so here. The needful variations, generation after generation, will be selected, and it will seem as if acquirements due to practice and habit were handed down to the next generation. The larger group, the herd among antelopes and cattle for instance, gains in influence at the expense of the smaller, the family. In the same way among men the importance of the family tends to dwindle, while that of the State tends to grow. It is said—I accept it only as a *ben trovato* story—that in French schools a catechism is taught. *Question:* My little boy, who protects you? *Answer:* The State. *Question:* My little boy, who educates you? *Answer:* The State. And so on. No doubt the State is encroaching on what was formerly the province of the family. Let us hope there will never be any good ground for adding to this apocryphal catechism the question and answer: "My little boy, who feeds you?" "The State."

A semblance of Lamarckism

We have seen now how parental guidance, or the tradition of the species, decide within certain limits the line of evolution, and make it appear that the results of habit and of exercise are transmitted to the next generation, as Lamarck maintained. Let us see whether this same principle holds when there is no particular guidance and no tradition to help its working. I will take a few instances which, I think, prove that it does. A snipe is a bird of the marshes, and his nest is made among the sedges and rushes, but Mr Seebohm, in his *Siberia in Europe*,[1] tells of snipe taking to arboreal habits. Flooded out, they had the intelligence to make their nests in trees. The "Paradise Ducks" in New Zealand, finding that they are disturbed when they nest on the ground, have been known to build in high trees and carry their young to the ground when they hatch out. Here we have the intelligence of the individual working without any guidance, parental or other. If variations in structure were required owing to the new habits thus formed, no doubt variations would follow in the wake of the habits, some of the ducks and the snipe being selected because they succeeded in adapting themselves to the new ways, and others passing away to the limbo of failures.

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[1] P. 127.

How fish become air-breathers

I will now try to explain, on this principle, some things that have happened in the course of evolution. Consider the life of fish in ponds. They are liable to find their pond drying up, thus depriving them of food, and, a still more instant need, of the breath of life. They must either migrate to a new pond or manage to get oxygen from the air till their pond fills up again. Even if they tramp it to another pond, they must for a time be air-breathers. The Climbing Perch, walking on his fins, goes in search of water, being equipped with a special apparatus which keeps his gills damp. The Lepidosiren (the Mudfish) and others wait covered with mud till rain comes, keeping some access to the air and becoming air-breathers for weeks and months. The Mudfish has developed lungs, which enable him to make light of times of drought. But when trials of this kind first came to the species they cannot have been thus equipped. They had swim-bladders, no doubt—I have already given an account of them[1]—and the swim-bladder is an organ homologous to our lungs, is in fact the same organ. But at the outset, however efficient as a swim-bladder, it must have been very rudimentary as a lung. Still it would do as a makeshift during a short period of drought. Exercise would increase its efficiency, and when a longer period came, the Mudfish, thus fortified, would be able to weather the crisis. His offspring would similarly have to make the best of pond life with its recurring times of desiccation. Those of them that could thus make shift would survive, while the less efficient would succumb. While habit was at work in the individual, evolution would be at work in the race. There would be variations in the matter of lung development retrograde or progressive, rendering mere habit and exercise nugatory for one individual, in another backing them up and making them easy and effective. Thus the individual, by making the utmost of his, as yet, rudimentary lungs, would be gaining time for evolution to furnish the species with a superior congenital endowment.

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[1] See p. 55.

The stag's antlers

Take another case, the one made so familiar by Mr Herbert Spencer. An integral part of his philosophy was the inheritance of acquired characteristics, "train the young, and the next generation will show the results of the training and will start at a higher level." The power of Natural Selection he always belittled, arguing and insisting that a number of co-operating variations are wanted simultaneously, and that there is no reason why they should not appear one by one and so be useless. In particular, he wrote much about the ponderous antlers of the stag, maintaining that they would be worse than useless if the neck that supports them did not become proportionately strong. Whereas if we attribute the whole growth—antlers and such neck muscles—to exercise, there is no difficulty. So he argued. But horns are not things which can be exercised, nor could any amount of butting and pommelling produce the stag's splendid antlers. We must look for another explanation. Suppose that a stag in the early days of the species had antlers of unusual weight. They might no doubt be a burden to carry. But whenever he was not lying down full length and resting, his neck would have to carry them. Thus exercise would make it stronger day by day. Even a short course of Sandow produces great results, but here is systematic exercise such as no human being has the perseverance for. Remember, too, that the antlers do not attain their full development in youth—a new tine is added each year—and there is a gradual increase in the weight to be carried. By means of exercise, then, the stag of early times would be able to put on, at any rate, the beggarly minimum of muscle required to carry his weight of antlers. Among his offspring would probably be some that were overweighted, whose necks were too weak even when exercise had done its utmost for them. They would be like ancient knights overburdened with their accoutrements. Some, on the other hand, would be able to carry their fine antlers easily, and use them effectively. These it would be who would win the prizes of the arena and be lords of the herd. Thus exercise can fill the gap with a temporary makeshift arrangement. The required variation will follow in due time. And so we can account for co-operating variations. If they do not arise simultaneously, yet the individual makes the most of his scanty endowment and somehow rubs along. At length a congenital variation arises to make good the deficit and put the species on a firm basis. In this way we can explain how it is that the stag can make light of his ponderous antlers, the elephant of his still more ponderous tusks. In the British Museum at South Kensington may be seen the tusk of an elephant 10 feet 2 inches in length, 24¼ inches in girth, and weighing 228 lb.! The weight of a pair of them 456 lb.! And this portentous burden was carried just in the way to make it most felt. Think what a heavy thing a rifle is to hold at arm's length. And yet, no doubt, the owner of these tusks thought their weight a mere bagatelle, the needful co-operating muscles and ligaments having arisen in due time on the principle I have tried to explain.

A boa constrictor's swallow

I will now give one or two more examples which presented the same kind of difficulty. There is the boa constrictor's habit of swallowing his victim whole, for which his teeth are specially adapted, for they have a backward slope and so do not stop its downward progress. His jaws are very loosely hinged, or rather not hinged at all, so as to allow of his swallowing creatures that seem bigger than himself in girth. He is able to protrude the end of his windpipe, so that it may not become blocked. Sometimes it hangs out at the side of his mouth, and sometimes in front: the fact that the two halves of the lower jaw have no bony connection makes this easier. Breathing during the long meal must be important. Though he will often go for half an hour without a respiration, it is not to be supposed that he can do so during this time of strain and effort. Here are a number of co-operating variations—teeth, loosely hinged jaws, windpipe. As it is, he often almost chokes during the process of swallowing his duck or his rabbit. What must the state of affairs have been when, long ago, the individual boa by desperate effort was gaining a respite for the species till at length in his descendants the needed variations should occur?

The mole

The mole has very strong forelegs and very strong muscles, springing from the breastbone, for working them. His burrowing requires great strength in that quarter. The breastbone has a keel, and suggests that of a bird. The eye has become very small; it is buried in his fur. Otherwise he would be no good at tunnelling. Here again are co-operating variations.

Eagles and other birds of prey

Cock birds are, as a rule, fighters, and in consequence polygamy tends to arise. But the tendency is kept in check by the fact that in most species the help of both parents is wanted to feed or to defend the young. It has actually arisen among the pheasants, the jungle fowl, the ruffs, and other species in which the young are born precocious, and to a great extent able to look after themselves. In birds of prey, fighting power is required in both sexes, and since the young are helpless for many days after birth, both parents must work to feed them. Were the males the better fighters, polygamy would arise, and that would not do. As a fact we find that the hens are the better men, and quite able to nip it in the bud. The hen peregrine falcon is the bird to hawk with. The tirzell, as the male is called, is comparatively feeble. And now to the argument: Natural Selection has been able to develop the fighting powers of both sexes, and at the same time to regulate the variations so as to bring about this exceptional relation between them. Or would Herbert Spencer have argued that the females must, generation after generation, have managed to defeat their lords in fair fight, and so gain a superiority in stature and muscular development as the inherited effect of exercise?

It is remarkable that in vultures, which are not great fighters but feed on carrion, we do not find this difference between the sexes.

I have now given several examples of types in which there are highly specialised features that depend for their efficiency on others equally specialised, a co-operation which, I have tried to show, has been brought about, not through the inheritance of acquired characters but, through the manipulation of variations by Natural Selection, the individual by strain and effort gaining a respite for the species when the variations did not appear simultaneously. The bird offers to my thinking a better example, than any type described here, of evolution proceeding harmoniously in a number of inter-dependent organs. But this point I have tried to bring out in an earlier chapter.[1]

Here I bring this small book with a big title, *Life and Evolution,* to an end. I have tried first to depict the micro-organisms, their structure, such as it is, and their way of life. From them we went on to the inhabitants of the sea, of its shore and surface waters, and of its depths. Reptiles next came upon the stage. Then in birds, the descendants of reptiles, we saw vitality at, perhaps, its highest, and we investigated the machinery by means of which they sail the air. After this we went back to the Amœba and the Infusorian, and found the first beginnings of mind in them. In crabs, chickens, dogs, monkeys we traced the development of intelligence till evolution culminated in man. And, lastly, we have pictured the working of Natural Selection, and seen it regulating the course of evolution from the lowest forms up to the highest.

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[1] Chapter v., see the opening pages.

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[(1) *An asterisk denotes that an explanation of the term is given at the page referred to;*
(2) *where there are several references, the more important are given in heavy type;*
(3) " *Contents* " = *Table of Contents.*]

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